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SEDIMENTOLOGY OF THE SIXTYMILE RIVER PLACER GRAVELS, YUKON TERRITORY

BY

© RHYS LECKIE HUGHES

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF Master of Science

DEPARTMENT OF GEOLOGY

EDMONTON, ALBERTA

FALL, 1986

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled The sedimentology of the Sixtymile River placer gravels, Yukon Territory submitted by Rhys Leckie Hughes in partial fulfilment of the requirements for the degree of Master of Science.

Frances J. Hein
(Supervisor)

Date: Sept. 10/86

DEDICATION (BY F.J. HEIN)

Rhys L. Hughes died tragically during the summer of 1986, while he was rewriting this version of the thesis for final submission. As his supervisor I have made the final (minor) grammatical changes to the text, and apologize for any passages of the text which may not read so smoothly. In doing this revision I have tried to preserve what I think was Rhys' intent both on the style and content. John England and support staff in the Department of Geology assisted in the preparation of this final version. Finally, I want to dedicate this thesis to Rhys -- a person who worked very hard and very dilligently on a project he was keenly interested in . In doing this work Rhys has contributed significantly to our understanding of the history and placer geology of the Sixtymile River area. He was also able to spend his time up North in an area that suited him well -- the Yukon.

" ... to those who see miraculous sights and envision all of the wonders hidden from the eye . ... hear multitudinous sounds and listen to the symphonies that silence brings. ... (Gwen Frostic, 1965) ."

ABSTRACT

The surficial sediments in the Sixtymile River area are mapped on airphotos as active and inactive alluvium, rock, colluvial veneers and blankets. Detailed measurements of the sedimentary structures and textures within representative outcrops of these deposits suggest that the sediments were deposited in a variety of environments, including: alluvial-fan, braided river, coarse-grained meandering river and colluvial valley-wall settings.

All bedrock surfaces and the immediately overlying gravels of the active and inactive alluvium are enriched in placer gold. The distribution of this water-laid placer is a function of both the hydraulics during the deposition of the gravels and the regional physiography and geomorpholocial evolution of the landforms. The preferred site of placer accumulation is the fan apex where flow became increasingly turbulent and the larger heavy mineral grains were quickly trapped in void spaces of the gravels.

Fluvial gravels range from massive and poorly-sorted to stratified/cross-stratified and well-sorted gravels. Fine-grained sands, silts and muds are massive to stratified, and are interpreted as bar-top and overbank deposits. Muddy matrix-supported gravels and massive silts blanket most of the alluvial fan and braidplain sequences. Proximal to distal down-valley trends within alluvial-fan deposits are evident by a change from massive or crudely-stratified gravel $\longrightarrow$ well-stratified gravel. Gravel of the alluvial braidplain are channel-lag, channel scour-and-fill and

massive gravel in proximal sites ⟶ stratified gravel in distal settings. Vertical sequences of coarse gravels from the valley-center of the Sixtymile River are characterized by coarse-grained, gravelly point bars within a meandering river system.

A sample of *in situ* wood yields a radiocarbon date of 26,080 ± 300 B P (Beta 13870). This sample was overlain by bone material of which yielded younger radiocarbon dates of 23,000 ± 640 BP (Beta-13864) and 21,160 ± 280 (Beta13876). This is the first *in situ* tree of full glacial age found in the Yukon. These three dates imply the presence of a large assemblage of herbivorous mammals living within an environment with a climate sufficiently warm and moist for the growth of trees. This climatic period occurred prior to the onset of cold and dry periglacial conditions within the unglaciated Beringia and also prior to the maximum extent of glacial conditions across the rest of North America.

ACKNOWLEDGEMENTS

The Geology Section, Department of Northern Affairs financed this work and provided logistical support. Discussion with O. L. Hughes, D. Harrington, S. R. Morison and F. Hein, all of whom visited the Sixtymile area, provided useful information and advice. I am particularly grateful to F. Hein of the University of Alberta for the guidance in preparation of the resulting MSc. thesis. R. Hale and J. Duke provided invaluable field assistance. This project would not have been possible without the assistance of all the placer miners in the Sixtymile area, who allowed access to their properties, and to whom I am most grateful.

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CHAPTER I. INTRODUCTION

A. PREVIOUS WORK

Miller Creek and four other small tributaries of the Sixtymile River (Figures 1 and 2) were the site of a rich placer gold discovery in 1892. The first important geological report on the Sixtymile River area is by Cockfield (1921) who described the regional geology, stratigraphy and the location and value of placer gold recovered by the early miners. At that time total gold production by hand mining and a small dredge operation was 50 million U.S. dollars of gold, at $300.00 U.S. per oz.

In the Sixtymile River area Cockfield (1921) provided notes on general stratigraphy of gravel sections in pits and shafts. Debicki (1983) described the location and stratigraphy of the active placer properties. Glasmacher (1984) described the petrology of the underlying bedrock in the same area and identified detrital mineral suites of nearly 50 sediment samples taken from a variety of settings.

McConnell (1905) was the first to describe the placer deposits of the now famous Klondike placer gravels of the Yukon. More recently Tempelman-Kluit (1982) interpreted the Klondike White Channel Gravels at Dago Hill, near Dawson City (Figure 1) as proximal, braided stream deposits of a 'Scott-type' system, using the classification of Miall (1978). He also noted the alteration of the White Channel gravels and suggested circulating

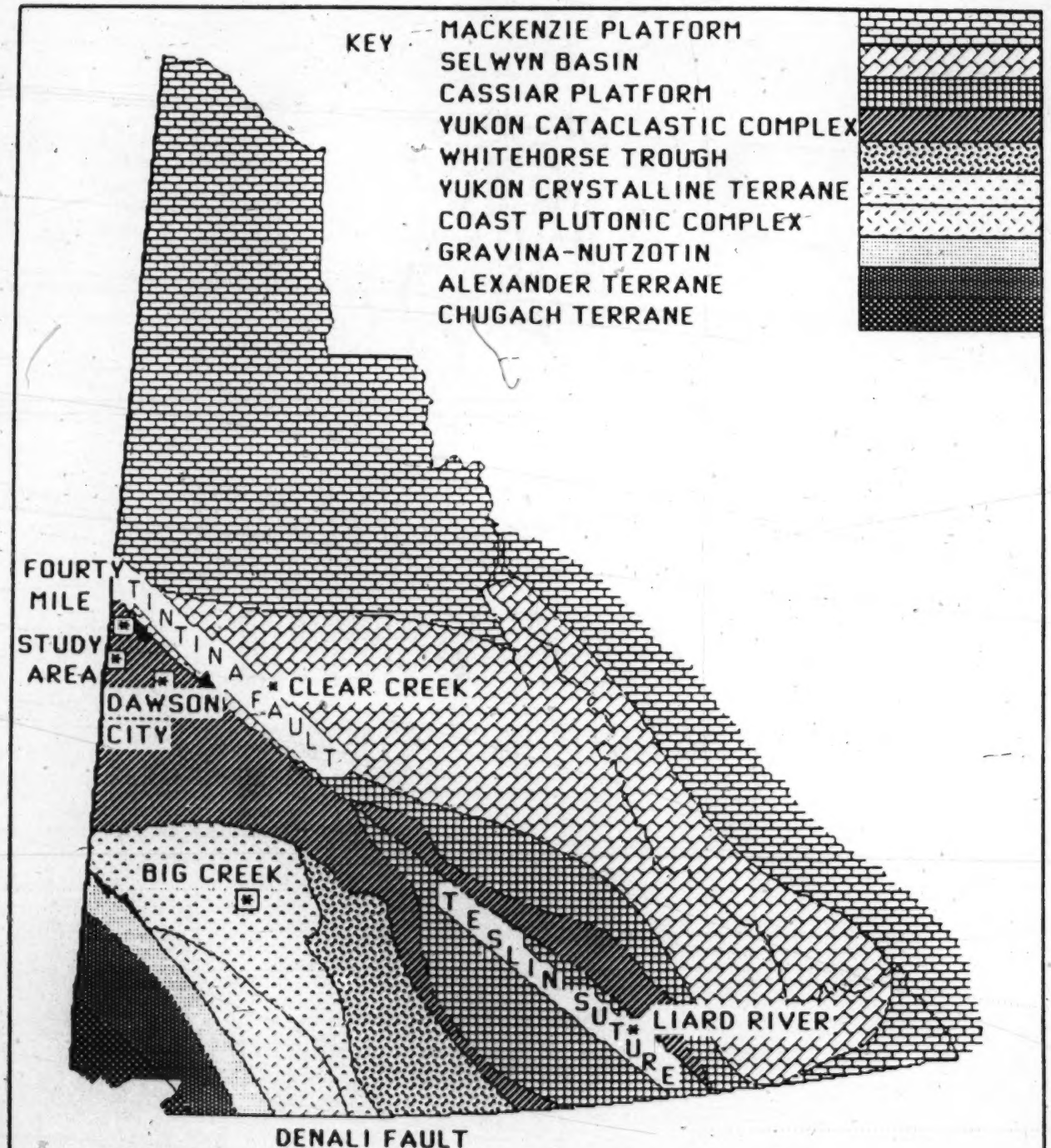

Figure 1 Map showing tectonic elements of the Yukon (from Tempelman-Kluit 1981) and location of study area Also shows other placer camps within the Yukon

groundwater may have been responsible for the alteration. Morison (1983, 1985a) conducted the first detailed study on the clastic sedimentology of placer deposits in the Yukon. He described the sedimentology of the Clear Creek fluvial valley-fill deposits (Figure 1) and suggested a similarity to the White Channel gravel. In more detailed studies on the sedimentary facies of the White Channel gravel, Morison (1985b) and Morison and Hein (in press) interpreted the gravels as proximal braided fluvial channel, floodplain and sediment-gravity flow deposits from colluvial slopes. Most recently, Dufresne (1986) indicated the clay alteration in the White Channel gravel was due to low temperature epithermal fluids. He suggests that anomalously high gold values in the gravels well above the bedrock, and gold in veins within the underlying bedrock, may be genetically related to the circulation of these fluids.

B. GENERAL GEOLOGY AND STRATIGRAPHY

Tempelman-Kluit (1982) and Monger et al. (1982) interpret the geology of the Yukon as reflecting the evolution of an accreted exotic terrain along the western margin of the North American continent. The study area is within the Yukon Cataclastic Complex, which is comprised of three assemblages of highly sheared and metamorphosed rocks that are thrust over less deformed North American strata of the Nasina Shelf and Cassiar Platform (Tempelman-Kluit, 1981). In ascending order the structural elements comprising the Yukon Cataclastic Complex include: 1) the basal Klondike schist (Nisutlin Allochton), 2) sheared ophiolites of the Anvil

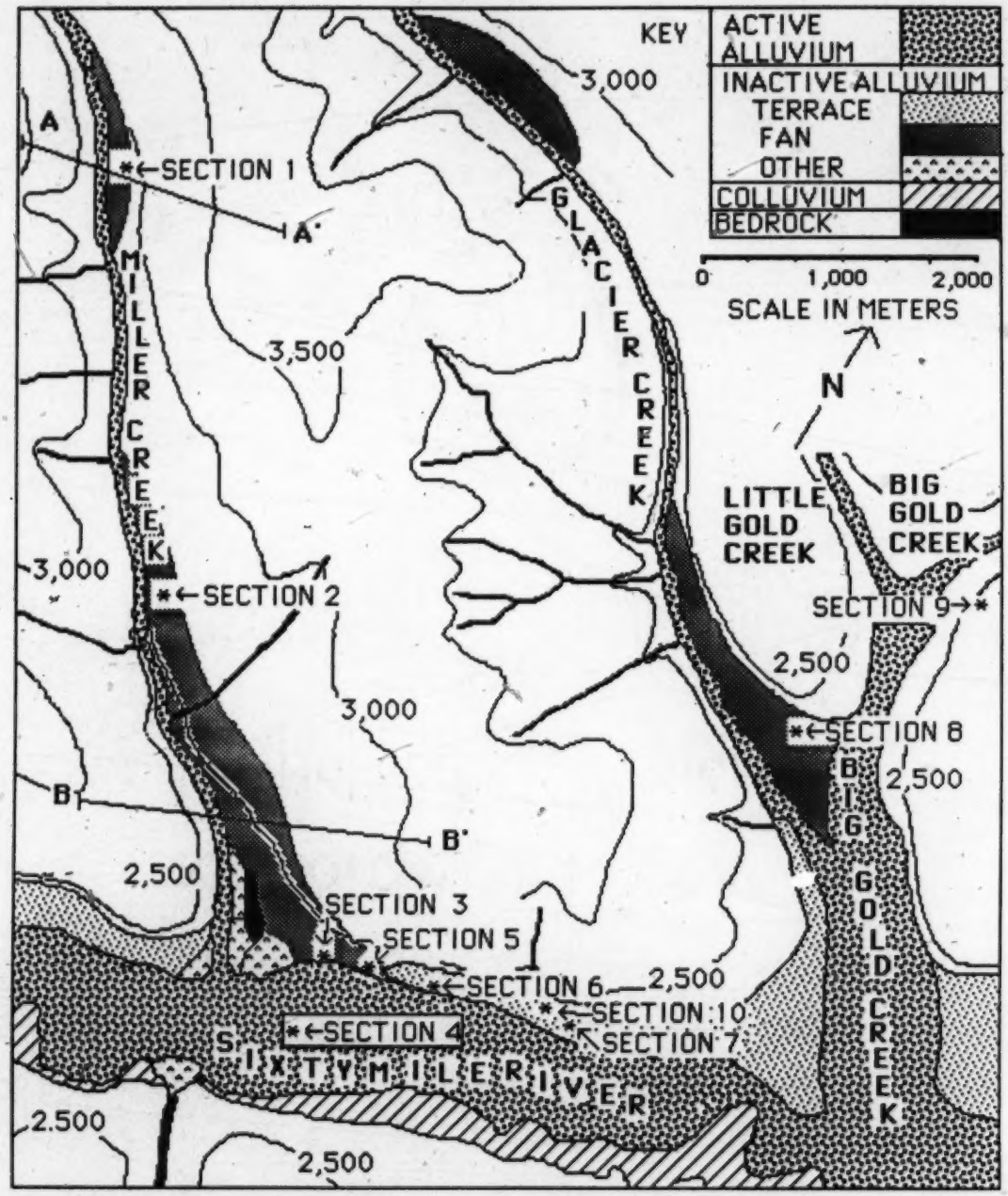

Figure 2. Location map for study area, showing section locations, creek names and types of surficial deposits.

Allochthon and, 3) the Simpson Allochthon, composed of sheared biotite granodiorite schist (Tempelman-Kluit, 1981). During the Tertiary dextral strike-slip motion (450-750 km of offset) occurred along the northwest-trending Tintina and Denali faults (Figure 1).

The Pelly Gneiss (a foliated muscovite, biotite granodiorite of assumed Paleozoic age) and the Klondike Schist (a chlorite, muscovite schist) outcrop immediately south of the study area. Metcalfe (1981) indicated a whole-rock Rb-Sr isochron age of 202 ± 11 Ma for the Klondike schist, with an estimated minimum age of the protolith of approximately 260 Ma. In the Sixtymile River area, the metamorphosed, Nasina Series basement is undated, but elsewhere these units are laterally traceable into Lower Ordovician to possibly Mississippian sediments of the Cassiar Platform (Tempelman-Kluit,1981).

The Nasina Series is overlain by volcanics which were mapped by Tempelman-Kluit (1974) as the Eocene (or younger) Carmacks Group. The andesites, dacites and tuffs of the Nasina Series underlie the gravels at Sections 3 – 7 in the Sixtymile River valley and Section 8 in the Glacier Creek valley. Locally, along the Sixtymile River, sandstone, shale and conglomerates underlie and are interbedded with volcanic rocks of the Carmacks Group (Tempelman-Kluit, 1974; Lowey, 1982). These interbedded sediments were described as moderately- to well-indurated, white feldspathic sandstones, pebble conglomerates and shales, with local lignite accumulations (Tempelman-Kluit, 1974; Lowey, 1982). A similar sequence

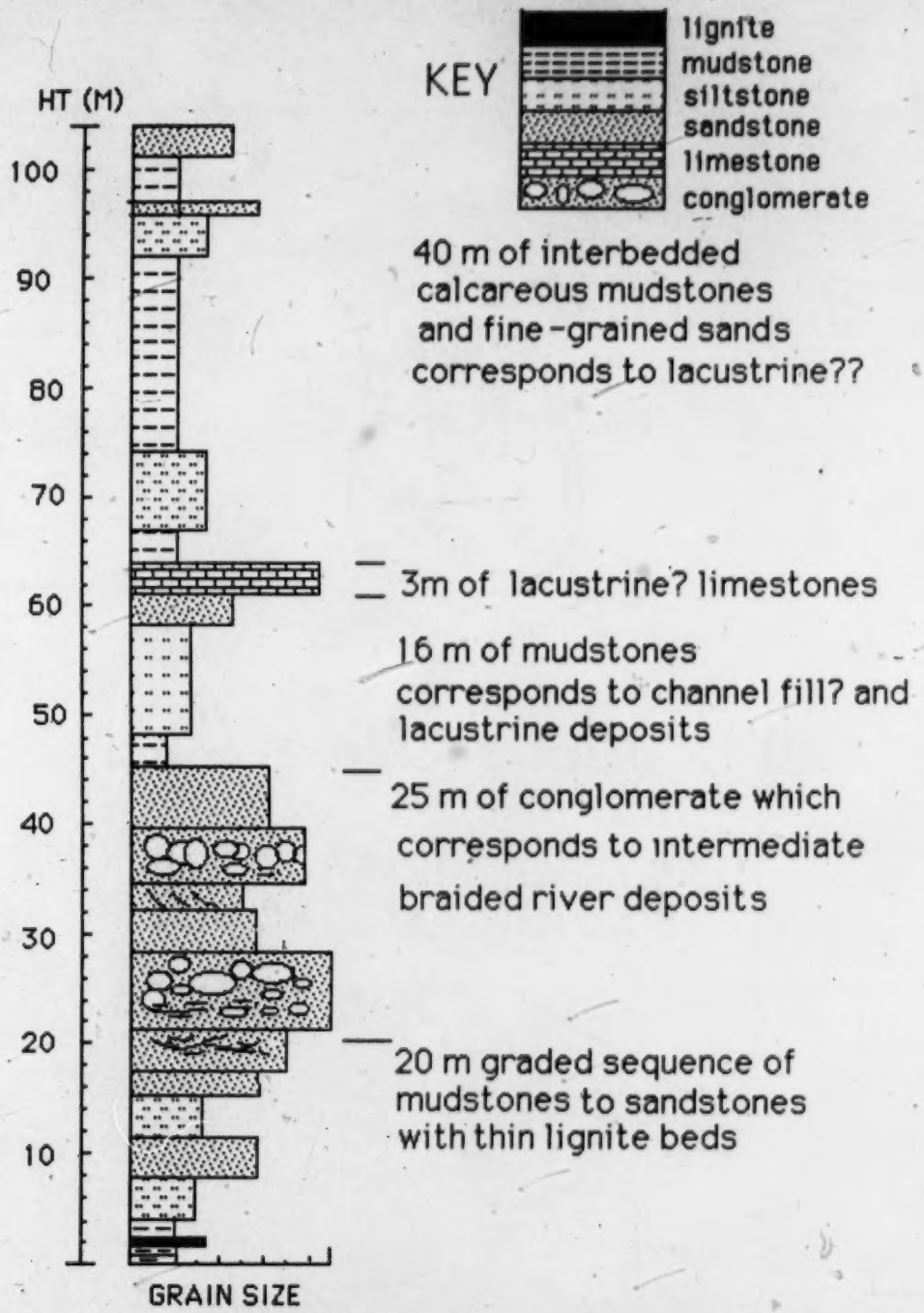

Figure 3. Vertical column for the sequence of Tertiary ? clastics at Section 9. Interpretations of depositional environments based on Lowey (1982).

of conglomerate, sandstone, mudstone and lignite was measured at Section 9 (Figures 2 and 3). The volcanics are overlain by flat-lying alkali-olivine flow basalts of the Quaternary Selkirk Group.

Cockfield (1921), Bostock (1948), and Tempelman-Kluit (1974) have suggested an Early Tertiary (possibly Eocene age) for the volcanic and intercalated clastics. This age is supported by Lowey's (1982) initial results of K-Ar dating of 51.4 ± 3.9 Ma obtained from a tuff bed interbedded within the sequence of clastics. However, palynomorphs indicate that the lignites in the Sixtymile River area may be Maestrichtian (74.5 - 66.4 Ma) (Lowey, 1982). Overall, the mapped vertical sequence at Section 9 (Figure 3) coarsens upwards and contains three of the four basic assemblages noted by Lowey (1982). However, the sequence of lacustrine muds in Section 9 is much thicker than those noted by Lowey (1982) and indicate a longer term transition to a lacustrine environment.

CHAPTER II. PURPOSE AND METHODS OF STUDY

A. PURPOSE

The purposes of this study are to : (1) describe the geomorphology, sedimentology and stratigraphy of the gold-bearing gravels and associated deposits at Miller Creek, (2) develop a facies scheme and facies summary to account for lateral and vertical facies transitions, (3) develop a paleogeographic model for the different depositional environments, and (4) relate the distribution of placer gold to the paleogeographic model.

This study contributes to our understanding of the sedimentology of coarse gravel deposits, especially the documentation of structures, textures and clast fabrics of coarse gravels in a variety of depositional environments. Within the study area eight well-exposed sections of frozen gravels were mapped laterally and vertically on a bed-by-bed basis. Grain-size and fabric analysis were done on selected beds. Analysis of these sections, based on facies concepts and the mechanics of sediment movement, will add to the understanding of coarse clastic deposits.

Within the Yukon the most important stratigraphic and paleoenvironmental studies have focused upon the palynology of lacustrine sediments such as those in the Old Crow Basin (i.e. Schweger and Matthews, 1985). Similar studies within the unglaciated part of the Yukon, such as

the the Sixtymile River area are rare, in part due to the paucity of lacustrine sediments suitable for palynological study.

The Sixtymile area is of considerable paleoenvironmental interest because radiocarbon dating of *in situ* wood at Section 7 (Figure 2) (Plate 21) yielded a date of 26,080 ± 300 B P (Beta -13870). This wood was collected beneath gravels containing a rich assemblage of dated mammalian remains (Beta - 8864 which yielded a date of 23,320 ± 640 BP and Beta -13869 which yielded a date of 21,160 ± 280 B P) (see Appendix A). This is the first finite date of full-glacial age obtained on wood from the unglaciated Yukon and clearly supports the two younger dates obtained from the bones. The wood material was clearly *in situ* , but unfortunately, the overlying fine-grained sediment and gravel (including the dated bones) are allocthonous. Therefore, a detailed analysis of the depositional environment of the clastics together with the associated bone and wood will help document an important, but poorly understood part of the Quaternary history within the Yukon.

Placer gold has been recovered from most of the tributaries to the Sixtymile River and all exposures within the study area were the result of placer mining. Investigation of the sedimentology and stratigrapy of the placer deposits will lead to a local model for placer formation and will aid in the understanding of placer formation throughout the Yukon.

B. METHODS OF STUDY

The first part of study involved section-measuring of outcrops on Miller Creek, Sixtymile River and Glacier Creek on a bed-by-bed basis. Sections of gravel were mapped vertically, and where possible, laterally. Notes taken in the field include descriptions of sedimentary structures and textures, grading and type of contacts between beds. At 30 locations grain-size measurements were taken of the a-axis of 10 largest clasts within beds to quantify the coarser fraction of the facies. Samples of sediments from each facies were wet sieved through a #10 sieve (U.S. Standard Sieve Number) to separate the sand, silt and mud from the gravel. Then the finer fractions were wet sieved through #18, #60, #120 and #230 mesh to obtain a more detailed grain-size distribution. Samples were then dried, weighed, and calculated as individual weight percentages. The percentage of mud was calculated from the difference between the initial sample weight and the total gravel and sand weight. Grain-size statistics are presented for each sample and summarized for each facies in Appendix B.

Pebble fabrics are important to aid in the measurement of paleoflow directions, the interpretation of depositional mechanisms and the reconstruction of the depositional environment. Therefore, at 15 sites the imbrication of 100 pebbles were noted as being either a- or b-axis imbricate. In order to insure than only non-sperical, disk-shaped clasts were used, only those pebbles with long axes greater than 2 cm and with an axial length ratio (a- to b-axis lengths) of at least 1.5:1 were measured.

Measurements were taken of the apparent trend and plunge of the imbricated a-b plane. Data were plotted as a- vs b-axis imbrication ratios, as rose diagrams of dip direction of the a-b plane and on a map of the study area as inferred paleoflow directions (see Appendix C).

In order to investigate the distribution of placer minerals within the study area, 29 bulk samples of gravels (1 cubic foot) were collected from beds representative of different facies in proximal versus distal sites. The bulk samples were sluiced and hand-panned (Figure 4), then evaluated by binocular microscope for the presence of gold (see Appendix D). The petrology of the gravel clasts was determined to help deliniate the provenance of gravel clasts. At 12 sites 50 cobble and boulder-size clasts were identified as to lithology (including the lithology of the 10 largest clasts) (see Appendix E). Finally, from three selected sites along the Sixtymile River valley, between Miller Creek and the Sixtymile River (Figure 2) organic material was collected and submitted for dating to the Geological Survey of Canada (see Appendix A).

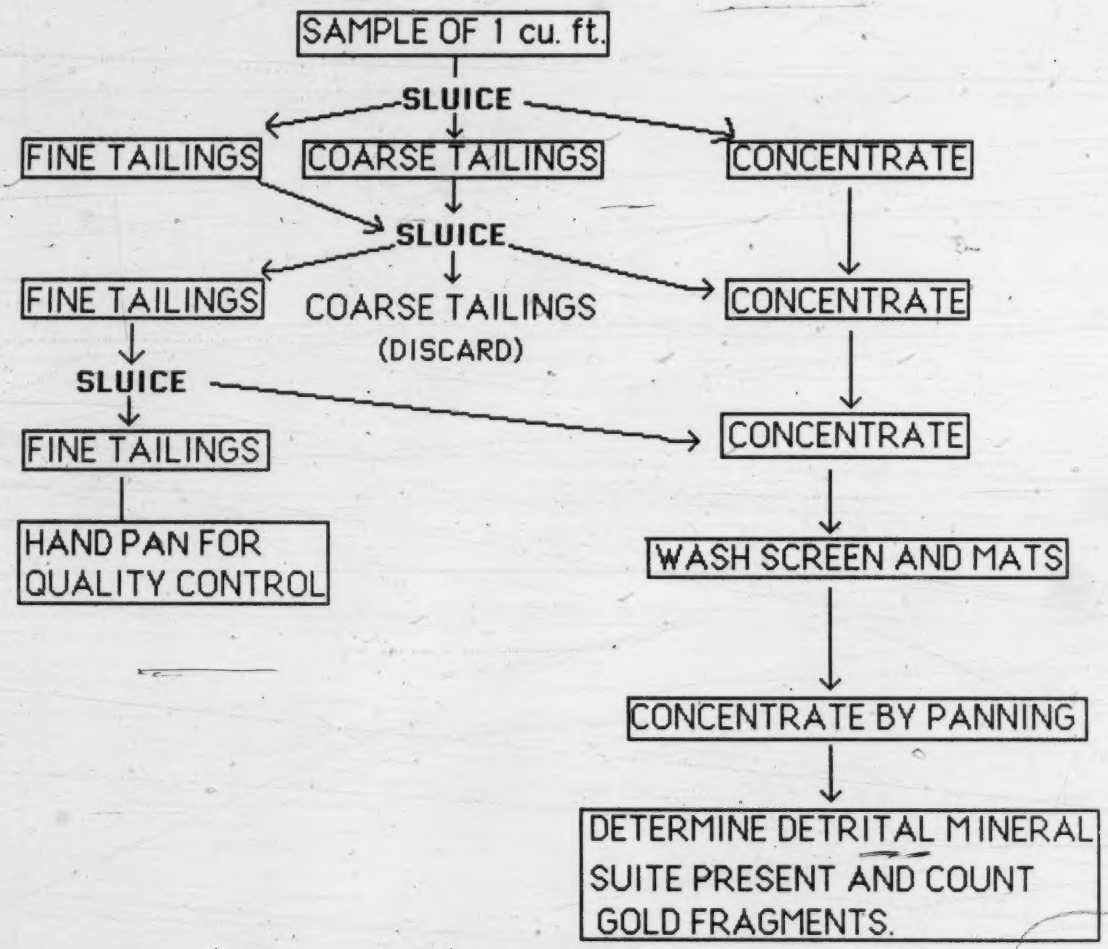

Figure 4. Flow diagram of method used in concentrating gold in which samples of gravel were separated in the field in a small sluice box.

CHAPTER III. GEOMORPHOLOGY, STRATIGRAPHY AND PERIGLACIAL FEATURES OF THE SIXTYMILE RIVER AREA.

A. GEOMORPHOLOGY

1) PHYSIOGRAPHY

In this part of the Yukon a rolling upland landscape formed during the Tertiary after deposition of the Carmacks Group volcanics and before the onset of White Channel Gravel valley-fill deposition (Bostock, 1948; Cockfield, 1921). The general physiography of the area is now a plateau at a general elevation of 1,300 m which has been deeply dissected by streams to a depth of 500 m to 1,000 m (Cockfield, 1921). Tempelman-Kluit (1981) suggests that this plateau was incised and eroded after the Eocene and before the Pliocene. He also proposed that prior to the Pliocene the Sixtymile River was a tributary to a system which drained southeast along the course of the present Yukon River, but in the opposite direction. The change from a southwesterly drainage to the present northwesterly course of the Yukon River occurred during the Pleistocene as a consquence of damming by glacial ice in the St. Elias Mountains (Tempelman-Kluit, 1981).

The physiography of Miller and Glacier Creeks (Figures 5a and 5b) consists of asymmetric valleys with steep northeast-facing and more

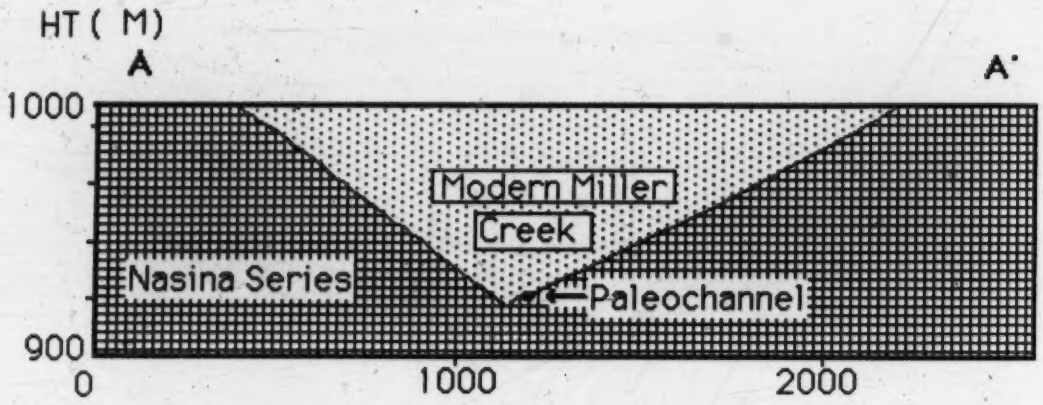

Figure 5a Cross-section A - A' showing position of paleochannel in headwaters of Miller Creek.

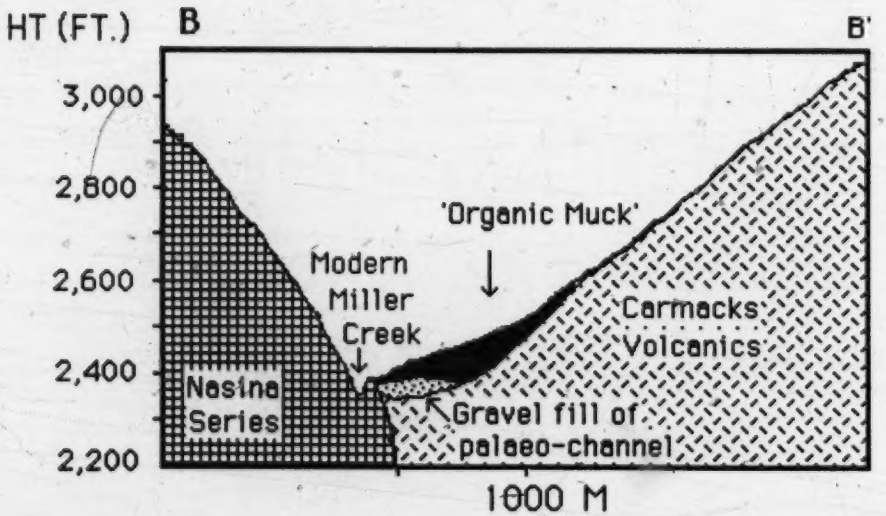

Figure 5b. Cross-section B - B' of upper Miller Creek which shows relative positions of the modern channel to gravel fill of the paleochannel and the colluvial blanket of 'organic muck'

gentle southwest-facing slopes. In the upper reaches of the creeks, narrow benches occur 20 m above the valley. Here the more gentle southwest-facing valley walls have terraces underlain by alluvial-fill sequences up to 10 m thick. In the lower part of Miller Creek a second, terrace, underlain by 20 m of alluvium, is found on the southwest-facing slope of the valley. Only an eroded remnant of a similar terrace exists in the lower part of Glacier Creek. The third, and largest terrace within the study area is found on the north side Sixtymile River valley (Figure 2). This terrace is visible on airphotos for approximately 10 km above Miller Creek and downstream is accordant with the bedrock terraces of the White Channel Gravels near Dawson City. Hughes (1970) suggested that incision and preservation of these terraces on bedrock benches above the valley floor between Dawson City and the Sixtymile River area resulted from Pliocene uplift of the Swede Dome.

2) SURFICIAL DEPOSITS AND LANDFORMS

Surficial materials within the study area (Figure 2) which are apparent on air photos include: 1) rock, 2) active and inactive alluvium, and 3) colluvial veneers and blankets. Some of the surficial deposits have been redeposited by debris flows, such as the small debris-flow lobe occurring at the mouth of the unnamed creek just south of Miller Creek (Figure 2).

Exposed bedrock is conspicuous as tors of resistant bedrock on

the tops of ridges and hills. These are features common in unglaciated regions which have experienced extensive periods of weathering in a periglacial climate. Rock is also exposed on steep slopes, particularly the north-east facing slopes of Miller and Glacier Creek valleys.

Active alluvium in the study area includes alluvium of the Sixtymile River (Figure 2) called the "Sixtymile River alluvial plain gravels" and valley-bottom gravels of the tributary creeks. The valley-bottom gravels have been completely reworked by placer mining. The active part of the Sixtymile River alluvial plain is dominated by a meandering, sinuous river developing gravel meander lobe sequences. Inactive alluvium within the study area includes: 1) gravels underlying the narrow benches in the upper reaches of Miller and Glacier creeks, 2) gravels underlying the terraces in the lower part of Miller and Glacier creeks, and 3) the "Sixtymile River terrace gravels" found on the north side of the Sixtymile River valley both upstream and downstream from Miller Creek (Figure 2). The hillslopes between the creeks in the study area are covered by a veneer of weathered colluvium. Colluvial blankets are common on the north-facing slopes of the Sixtymile River. Here, deposits < 2 m thick are called colluvial "veneers;" deposits > 2 m thick are called colluvial "blankets".

The major landforms in the study area include: relict and incised alluvial fans and alluvial valley-fill. At the mouth of Miller Creek, near the confluence with the Sixtymile River (Figures 2 and 5b), a bedrock

high separates recent valley-bottom alluvium from older valley-fill 12 (~ m thick). Between Sections 2 and 3 (Figure 2) this alluvium was deposited in a confined valley and will be referred to as "paleo-Miller Creek sediments". At Section 5, gravels of the "paleo-Miller Creek" were not confined by the valley walls, and where they debouched into the main valley of the Sixtymile River, they form an alluvial fan.

The terminus of the alluvial-fan gravels at Section 5 is planar because of erosion by the Sixtymile River on the north side of the trunk valley. During aggradation in the "paleo-Miller Creek" valley, the Sixtymile River eroded and reworked part of the paleo-Miller Creek sediments, preventing the further growth of an alluvial fan into the valley of the Sixtymile River. Within the Glacier Creek valley , at the confluence of Glacier and Big Gold Creeks, only the remnants of the incised alluvial fan/alluvial fill are visible.

B. STRATIGRAPHY

The stratigraphy of the Quaternary gravels within the study area is summarized below in the descriptions of the eight largest sections.

SECTION 1 is comprised of 4.0 - 5.0 m of poorly-sorted gravel located along Miller Creek approximately 5.5 km upstream from its confluence with the Sixtymile River (Figure 2). This gravel occurs as

valley-fill alluvium underlying the terrace on the northwest slope of the valley (Plate 2).

SECTION 2 is located approximately 100 m north of Miller Creek and 2.5 km upstream from its confluence with the Sixymile River (Figure 2). These gravels underlie the broad terrace that extends upstream from the mouth of Miller Creek. This section is characterized by 11.2 m of massive gravel with minor sand, capped by 5.0 m of interstratified gravels and muds (Figure 24a).

SECTION 3 is located in the "paleo-Miller Creek" valley approximately 0.6 km downstream from the confluence of Miller Creek and the Sixtymile River (Figure 2). This section is characterized by 5.5 m of silt capping 16.0 m of massive gravel with minor massive silt and sand. At the base of the section 2.0 m of interbedded clay, silt and sand are found capping 2.0 m of massive gravel (Figure 24b).

Two organic samples from Section 3 were submitted for radiocarbon dating. The stratigraphically lowest sample (GSC - 3934) was collected from a 15 cm thick peat horizon interstratified within the gravels at 8.1 m below the upper surface and 21.1 m above bedrock. It yielded a date of > 42,000 B. P. The stratigraphically highest sample (GSC - 4032) was collected from a 40 cm thick wood horizon resting directly on the uppermost gravel. This wood was overlain by 5.0 m of massive silt and yielded a radiocarbon date of > 40,000 B. P.

SECTION 4 is located in the active alluvial plain of the Sixtymile River approximately 0.50 km downstream from the mouth of Miller Creek (Figure 2). This section is characterized by 3.0 m of stratified and cross-stratified gravel overlain by 1.0 m of cross-stratified sand (Foldout C).

SECTION 5 is located on the Sixtymile River terrace approximately 1.6 km downstream from the mouth of Miller Creek (Figure 2). This section is characterized of 4.0 m of silts capping 3.0 m of horizontally stratified gravels that overlay 2.0 m of massive gravel (Figure 24c).

SECTION 6 is located on the Sixtymile River terrace approximately 1.9 km downstream from the mouth of Miller Creek (Figure 2). The sediments consist of 7.0 m of silt and 8.9 m of matrix-supported gravel overlaying 2.0 m of massive gravel (Figure 23d).

SECTIONS 7a, 7b and 7c are located on the Sixtymile River terrace approximately 2.4 km downstream from the mouth of Miller Creek (Figure 2). Section 7a consists of approximately 4.4 m of silt capping 1.0 m of matrix-supported gravel overlying a 3.0 m fining-upward sequence of gravel, sand and mud (Figure 23e). Sections 7b and 7c (Figures 23f and 23g) are the lateral equivalents of Section 7a measured within 10 m of the larger vertical column. They show details of the transition between the fining-upward sequence and the matrix-supported gravel. Direct

confirmation for the age of these sediments was provided by an *in situ* tree root buried in the silts at 2.6 m in Section 7c, which yielded a radiocarbon date of 26,080 ± 300 B. P. (Figure 23g) (Plate 6). The two other radiocarbon dates obtained from this section are based on bone samples collected from the mud-matrix supported gravel between 3.0 and 4.0 m in Section 7a. Sample Beta - 8864 yielded a radiocarbon date of 23,320 ± 640 B.P. and sample Beta -13869 yielded a date of 21,160 ± 280 B.P. (see Appendix A) .

SECTION 8 is located on a terrace 6.0 m above Glacier Creek immediately upstream of its confluence with Big Gold Creek. This section consists of approximately 7.0 m of interstratified gravels and minor sand.

SECTION 10 is located on the Sixtymile River terrace approximately 2.0 km downstream of the mouth of Miller Creek. This section consists of 4.0 - 5.0 m of silts capping 3.0 m of interbedded sands overlying 2.0 m of gravel.

C. PERIGLACIAL FEATURES.

Although most Quaternary geology in Canada is concerned with the advance and retreat of glaciers, this region of the Yukon is outside the area affected by the last three Cordilleran ice advances. Although unglaciated, this area was strongly influenced by a cold climate as

indicated by cryogenic features. These cryogenic features include: 1) a gravel ice-wedge cast and cryoturbated gravels and sands occurring at 2.1 m in Section 2 in the Miller Creek valley, 2) an ice-wedge cast in sands at 8 m above bedrock in Section 5 in the Miller Creek valley, 3) inactive massive ice wedges in fine silts between 4.0 - 8.5 m at Section 6 in the Sixtymile River valley, 4) ice-wedge casts in gravels at Section 4 in the Sixtymile River valley, and 5) the occurrence of permafrost throughout all of the surficial materials in the area.

Pewe (1973) in a study of similar periglacial features in the Tanana Upland of Alaska suggested a mean annual air temperature of -6 ^{0}C would be required for active ice wedges. Other well documented ice wedge casts are found throughout the Yukon. Of particular importance are the ice wedge casts found in the Old Crow Basin (Mathews and Schewegar, 1985). Other casts similar to those in this study area are found in the White Channel gravel (Morison, 1985a).

Ice-wedge casts at Section 2 and Section 3 in the Miller Creek valley represent the onset of a cooler climate than present during aggradation of the valley-fill alluvium. The two radiocarbon dates at Section 3 indicate these casts formed prior to 42,000 B. P. However, without further dating control, correlation to sections in the Old Crow Basin and the White Channel gravels near Dawson City is not possible. The two ice-wedge casts at Section 4 in the Sixtymile River valley begin in the gravels and then penetrate the bedrock for approximately

1.0 m (Figure A). Although these ice-wedge casts are not directly dated, it is suggested that this part of the Sixtymile River alluvial plain is probably younger than 25,000 B. P. and that these ice wedge casts date from the last full glacial stage. Finally, massive ice wedge casts are found within the thick silts at Section 7. These cryoturbated silts occur above the beds radiocarbon dated between 26,000 and 21,000 B.P. and therefore were probably formed during during the late Wisconsin glaciation .

D. INTERPRETATION

The asymmetric valley profile in the upper and lower part of Miller and Glacier Creeks suggests lateral migration and subsequent incision of the creeks. This resulted in preservation of fluvial gravels under the terraces. The gravels underlying the terrace at Section 1 in the Miller Creek valley were probably once continuous with the broader terrace in the Miller Creek valley between Sections 2 and 3, with the intervening terrace between these sections being eroded during incision of Miller Creek.

Radiocarbon dates from directly above the stratigraphically highest gravels at Section 3 in the paleo-Miller Creek gravels suggest that the vertical aggradation of the "paleo-Miller Creek gravels" was completed by 40,000 B. P . The ice-wedge casts within Sections 2 and 3 indicate the period of aggradation of these gravels spans at least one periglacial

interval prior to 40,000 B. P. As shown later in this thesis, the gravels at Section 3 prograded the Sixtymile River terrace. Therefore, the >42,000 B. P. date at Section 3 is a minimum date for the formation of the Sixtymile River terrace.

Ager (1982) stated that no dated tree-size wood has yet been found from full-glacial deposits (older that 12,000 B. P. and younger than 26,000 B. P.). Therefore the date of 26,080 ± 300 B. P. obtained from the tree root at Section 7 is important in interpreting the paleoclimatology of the Yukon because it suggests that the climate at that time was sufficiently warm for the growth of trees in the Sixtymile, possibly as a gallery forest. In addition the absence of other wood dates in the Yukon from this time suggests the trees growing in the Sixtymile River valley may have been one of the few surviving stands of trees in eastern Beringia prior to the onset of the late Wisconsin glaciation.

The eight largest sections within the study area are dominated by clast-supported gravel, matrix-supported gravel and silt. Sands are less abundant. Questions concerning the distribution of the placer gold and the correct sedimentological interpretations of mud-matrix supported gravels containing bone can only be answered once the depositional envirionments of these sediments is understood. The hydraulic conditions during the transportation of the gravels and silts and its relationship to the depositional environment of the sediments is considered in Chapter V.

CHAPTER IV. INTERPRETATION OF SEDIMENTARY TEXURES AND STRUCTURES

A. STREAMFLOW: ALLUVIAL FANS AND BRAIDED ALLUVIUM

The purpose of this chapter is to outline current interpretations of gravel sedimentary textures and structures. These textures and structures are used to describe and interpret lithofacies in Chapter V. The topic is limited in scope to descriptions of those textures and structures found in alluvium of braided streams, alluvial fans and on valley-walls.

Texture, structure and fabric analyses of alluvial fans and braided streams and, to a lesser extent, subareal debris flows are documented in studies of alluvial fans (Blissenbach,1954; Bull,1977; Steel et al.,1977; Nilsen 1982), modern rivers (Smith,1974; Hein and Walker,1977; Church and Jones,1982; Hein,1984; Southard et al., 1984), sandur (Rust,1972; Bradley et al.,1972; Fahnestock and Bradley, 1973; Boothyrood and Ashley, 1975; Boothyrood and Nummendal, 1978), and on valley-walls (Johnson, 1970; Morison and Hein, in press).

1. *SIZE DISTRIBUTIONS AND SORTING*

Fan-head and fan-channel gravels are angular and poorly-sorted

gravels which are texturally similar to weathered bedrock. The degree of immaturity in both the size-distribution of the clast and matrix is related to a local provenance and minimal reworking of the gravel. Well documented down-fan trends include a decrease in the mean and maximum grain sizes (Blissenbach, 1954). The most accurate measure of progressive clast-size reduction down-fan is the measure of the maximum intermediate (b) axis which shows an exponentially decreasing relationship . Grain-size changes of gravel alluvium in major valleys and on alluvial plains occur as different size clasts respond to shear stress on the bed by different modes and rates of movement. For gravel clasts the most realistic type of movement is rolling of the clast about a pivot formed by other clasts (Middleton and Southard, 1984). Sorting by this tractional movement is less efficient than sorting by suspension, but in alluvium, varying hydraulic conditions act to sort all of the sediment load into different parts of the system.

2. GRADING

Grading refers to a progressive clast-size change within an individual bed. Both normal and inverse grading in fluvial gravels imply that processes of transport and deposition sort bedload into different sizes. Normal grading of clast size indicates that the flow strength was diminishing during deposition. Grading in gravels can be used to infer changes in either forces acting on the bed or variations in flow velocity. However, major problems exist in the selection of criteria by which

grain size can be used to infer paleoflow parameters. Problems associated with the variability of sediment entrainment are particularily difficult to solve (Church, 1978).

3. HORIZONTAL STRATIFICATION AND CROSS-STRATIFICATION

Sedimentary structures in gravel alluvium are commonly defined by layers of clast-supported, matrix-filled gravels of different grain size. Less common are those structures characterized by changes in clast fabric orientation or alternations of sandy matrix-filled gravels with openwork gravel. Harms et al., (1982) have shown that in some cases alternating sand and gravel layers may imply only a slight fluctuation in flow strength. Bluck (1976) suggested that pockets of openwork texture may be due to post-depositional winnowing of the matrix. Smith (1974) interpreted the occurrence of openwork fine granule-sized gravel and sandy interbeds within coarse matrix-filled gravels as recording fluctuating discharge levels.

Four major types of stratification occur in coarse-grained braided alluvium: 1) horizontal stratification, 2) planar tabular cross-bedding, 3) trough cross-bedding, and 4) large-scale cross-bedding and lateral accretion cross-bedding. Horizontal stratification is most often described in outwash-plain (Hein and Walker, 1977) dominated by rapidly shifting braid channels with longitudinal or diagonal braidbars that develop from thin diffuse gravel sheets. Bars in these proximal reaches

are mainly diagonal or longitudinal, comprised of coarse, poorly-sorted gravel deposited as crude horizontal layers or low-angle cross-stratification (Smith, 1970). Similar crude horizontal stratification occurs in alluvial-fan and is usually attributed to deposition from unchannelized "sheet" floods (Bull, 1977). Growth of transverse bars and their associated slip faces in distal reaches of rivers results in the formation of planar-tabular or wedge-shaped cross-beds on the downstream margin of bars (Smith, 1970). Trough cross-stratification is the product of migrating dunes in channels (Harms et al., 1982).

Attempts have been made by Rust (1977), Hein (1984) and Smith (1985) to clarify the relationship between the origin and types of stratification in modern rivers. Development of crudely-defined horizontal to low-angle stratification was related to the progradation of longitudinal and diagonal bar margins; high angle planar tabular cross-strata is associated with the formation of steep bar margins. The role of rapid decreases in fluid and sediment discharge in the creation of cross-stratification was discussed by Hein and Walker (1977). Their model suggests that angle-of-repose cross-stratification arises when fluid discharge (Qf) and sediment discharge (Qs) across an incipient bar core decline rapidly after formation of a diffuse gravel sheet. Under these reduced fluid and sediment discharges, vertical aggradation dominates over downstream migration, resulting in the development of angle-of-repose foresets. By contrast, low-angle stratification forms

when the rate of migration is about the same as the rate of vertical aggradation, as in the case of longitudinal or diagonal bars. In these cases, no angle-of-repose foresets are developed -- at most the bars form riffle margins. Upon progradation the riffle margins produce horizontal to low-angle stratification (Hein and Walker, 1977; Hein, 1984).

4. GRAVEL FABRICS

Fabric refers to the spatial orientation of clasts in a deposit. Gravel fabric may be measured by taking the strike and dip of the a-b planes of elongate and flattish clasts within a bed. In coarse fluvial gravels, which may lack other sedimentary structures, gravel fabric may also be used to infer possible mechanisms of deposition. Preferred fabrics arise because gravel clasts become orientated with their maximum projected area normal to the flow (Harms et al., 1982).

In braided alluvium the most prevalent orientation in gravel deposited on subhorizontal surfaces is a tractional "rolling fabric" with an a-axis transverse, b-axis imbricate (dipping upstream) orientation (Johansson, 1965; Rust, 1975; Hein, 1984), although the orientation of some clasts may also be normal to the flow or both parallel and normal (i.e. bimodal) (Johansson, 1965; Hein, 1984). In braided outwash systems of the Canadian Rockies, Hein (1984) found that the preferred orientation of the a-axes of the clasts on braid bars is current-transverse, whereas

the b-axes of clasts were imbricate upstream. In the same study, the a-axes of smaller clasts within the channel were parallel to the flow, whereas the a-axes of larger clasts were normal to flow. The presence of bimodal and polymodal patterns were interpreted as reflecting complex current patterns flowing across bartops, around bar fronts or in point-bar swales, or due to reworking of exposed gravel bars or flats during successive high flows (Hein, 1984).

B. DEBRIS FLOWS

Middleton and Hampton (1973) classified sediment-gravity flows into four types: debris flows, grain flows, turbidity currents and fluidized flows based on the type of sediment-support mechanism during transport. Subareal debris flows were defined as gravity-propelled movements of sediment-water mixtures in which grains are supported above the bed by the strength and buoyancy of a clay/water matrix (Middleton and Hampton, 1973). Lowe (1979, 1982) proposed that sediment-gravity flows be classified by their rheological behavior into debris flows with plastic behavior and fluidal flows with viscous fluid behavior (grain flows). Debris flows exhibiting plastic behavior are most important to this study and are discussed below.

1. *MECHANICS OF DEBRIS-FLOW MOVEMENT.*

A Newtonian fluid exhibits a rate of deformation which is

proportional to the force per unit area (shear stress) according to Newton's Law of Viscosity . In Newtonian fluids the viscosity relates the shear stress acting on the fluid to its rate of shear (Hampton et al. 1984) . Non-Newtonian fluids respond to shear stress in such a way that the coefficient of viscosity is no longer a constant, i.e. a non-Newtonian fluid has a viscosity that varies with the rate of shear. If the dispersion has strength, and no deformation takes place until a critical shear stress has been exceeded, then the fluid is a "Bingham plastic." In this study the resultant flow will be referred to as a "plastic debris flow." Bingham plastics are non-Newtonian high concentration fluid dispersions that vary in strength and velocity with the rate of applied shear (Johnson,1970; Hampton 1972, 1975) Rheological models of Bingham plastics are the most suitable for describing types of fluid dispersions having a yield strength which must be exceeded before deformation can occur and which exhibit a linear relationship between shear strain and applied stress above the yield strength (Johnson, 1970; Shultz, 1984). In this model it is possible to differentiate between cohesional effects of the matrix and effects of frictional interactions between clasts.

Schultz (1984) distinguished four types of debris flows, three of which are applicable to this study: (1) plastic debris flows with substantial plastic yield strengths capable of transporting large boulders, (2) clast-rich debris flows in which flow mobility is dominated by friction rather than cohesion and (3) slurries with low yield strengths that are characterized by the lack or extreme reduction

of the rigid-plug layer.

A distinction has also been made between types of debris flows (essentially plastic debris flows that have strength) and "hyperconcentrated flows". The term "hyperconcentrated flows" was first applied by Beverage and Culbertson (1964) to visibly turbulent flows which have sediment concentrations between 40 - 80 wt%.

Experimental work by Hampton (1972) indicated that clast support in a plastic debris flow is provided by the matrix strength and the low density contrast between the clasts and matrix. The strength, density and apparent viscosity of the matrix are controlled by the surface electrostatic forces (Fisher, 1971). More recent theoretical work by Hampton (1975) indicated that for clasts greater than six centimeters in diameter buoyancy (the force resulting from loading or displacement of the fluid and the matrix by the clasts) is necessary for clast support. The additional support provided by buoyancy, especially under conditions of high clast concentrations, may allow for the transport of large boulders, or the formation of flows with a low percentage of mud matrix. Also dispersive pressures associated with large amounts of clast interaction in high-concentration flows may be an additional mechanism for clast support (Lowe, 1982).

2. TEXTURES IN DEBRIS-FLOW DEPOSITS

Debris flow movement has been observed and modelled by Johnson (1970). During movement of debris flows, a rigid plug rides passively over a basal region experiencing applied shear stresses which exceed the fluid yield strength. Sedimentary textures, particularly the grading and sedimentary fabric, depend upon the internal nature of the flow -- whether it is turbulent or laminar.

Hampton et al. (1984) showed that using typical estimates for shear strengths, critical velocities and viscosities derived from observations of other studies (Johnson, 1970), the critical velocity of 3 m/sec is necessary for the transition from laminar to turbulent flow. This may be reached by some thicker debris flows on steep slopes. Therefore, the flow conditions in some larger debris flows are at least partially turbulent (Middleton and Southard, 1984). Nemec and Steel (1984) indicate that as a debris flow becomes more turbulent, normal grading within the flow will develop. Unfortunately, few field studies include descriptions of structures and textural fabrics developed in this type of flow.

In plastic debris flows (characterized by high-strengths and viscous interactions between the clasts) inverse grading occurs within the basal shearing zone. The basal shear zone most commonly occurs as a mud-rich, relatively clast-free region only a few centimeters thick

(Schultz, 1984). Grading is rarely documented in ancient deposits, but has been reported as partially inverse graded beds (Nemec and Steel 1984; Gloppen and Steel, 1981). Examples of fully inversely graded beds are less common in the literature. Products of more dilute and probably "pseudoplastic" fine-grain debris flows would yield inverse-to-normally graded or, ungraded to normally graded deposits in coarser flows (Schultz, 1984).

Several different theories try to explain the pressures and forces in the basal shear zone that give rise to inverse grading. In the earliest work Bagnold (1954) suggested that the shear zone has greater grain mobility that develops dispersive pressures favoring the upward movement of large grains. Fisher (1971) suggested that this zone is a region of upward decrease in pressure gradients (as a result of velocity increases) that displace clasts upward. Middleton (1970) proposed a "kinetic sieve mechanism" during movement of the bed to explain inverse grading. This mechanism depends upon the tendency of smaller particles to fall into the spaces between the larger particles. Thus, the kinetic interactions between the particles during movement displaces the larger particles towards the upper surface of the flow.

3. CLAST FABRICS IN DEBRIS-FLOW DEPOSITS

Clast-fabric studies on subareal debris flows which show prefered orientations are rare (see Fisher, 1971). Middleton and Hampton (1973)

and Pierson (1981) all failed to effectively define an imbrication pattern for debris flows. Lindsay (1978) developed a computer simulation of clast alignment in which shearing in a laminar, viscous fluid-flow aligned clasts parallel to flow in a preferred a-axis upstream fabric, which tended to degrade and reappear in a cyclical pattern. He found that this a-axis fabric was recorded in examples of mud flows from the Permian Pagoda Formation in Antarctica. Other types of clast imbrication have also been mentioned including a-axis or b-axis upflow imbrication (Nemec and Steel,1984). The number and importance of clast interactions and the relative importance of dispersive pressures influence the type of clast imbrication. These factors will differ between flows and clast imbrication patterns may vary considerably (Nemec and Steel, 1984).

C HYPERCONCENTRATED FLOOD FLOWS

On alluvial fans, depositional units have been distinguished which cannot be attributed to truly viscous debris-flows or dilute stream flows (Schultz, 1984). Such deposits show properties intermediate between these two end-members. Only recently have such deposits come to attention, and unfortunately the documentation of their sedimentology has not been complemented by mechanical flow studies in the laboratory. Beverage and Culbertson (1964) applied the term "hyperconcentrated flows" to visibly turbulent flows which have sediment concentrations between 40 - 80 wt%. Most recently (Smith, 1986) has described the distinct textures of these

deposits as: poor sorting, distribution normal grading, and a matrix which is poorly sorted and contains very coarse-grained sands and pebbles. The fabric developed is a function of grain size: larger clasts are a-axis flow-transverse and b-axis imbricate upstream (tractional deposition), smaller clasts are a-axis flow-parallel and a-axis imbricate upstream, suggesting rapid deposition from a dispersion above the bed. Turbulence is the primary sediment-support mechanism, aided by grain interactions in the high concentration dispersion (Smith, 1986).

CHAPTER V. FACIES DESCRIPTIONS AND INTERPRETATIONS

The term 'facies' will be used in the modern sense given by DeRaaf et al. (1965) who distinguish sedimentary facies on the basis of lithological, structural and organic aspects as visible in the field. Because of the absence of biogenic structures in the sections studied, throughout the rest of the text the term "facies" will be used as a synonym for "lithofacies". The following description of the twelve facies interpreted to characterise the sediments has been summarized in Table 1.

Listed in decreasing order of abundance, sediments within the study area include: boulder to pebble gravel, sandy pebble gravel, silt, sand and mud. Facies were distinguished on the basis of: 1) primary sedimentary structures, including trough cross-bedding, low-angle cross-bedding, planar-tabular cross-bedding with angular foreset contacts, planar wedge cross-bedding, horizontal bedding and convolute lamination, 2) textures, including clast-supported and openwork, clast-supported and matrix-filled or matrix-supported gravels, 3) grading, including inverse and normal grading, and 4) sedimentary fabric, including ratios of a- to b-axis imbrication (Table 2).

In the description of the facies, (D 10) refers to the mean a-axis length (in centimeters) of ten largest clasts, (MX) refers to the maximum clast size (in centimeters) and (TH) refers to the mean bed thickness (in centimeters). All sediments within the study area are permanently frozen

TABLE 1 SUMMARY FACIES DESCRIPTIONS AND INTERPRETATIONS

Facies	Lithotype	Angularity/Sorting	Structures & Textures	Interpretation
1	gravel	A, poorly sorted	massive	proximal hyperconcentrated flood flow" deposits or talus
2	gravel	A-Sa, poorly sorted	massive to normally graded	residual lag gravels
3	gravel	Sa-Sr, poor to moderately sorting	massive to crudely stratified	channel and scour fill, occurs in concave up lenses
4	gravel	A-Sa, moderately-well sorted	massive to crude horizontal stratification, mud- matrix supported, inversely graded	cohesive, viscous debris flows
5	gravel	Sr, moderately-well sorted	large-scale single and multiple cross beds	large-scale lateral accretion cross beds; a product of migrating point bars
6	gravel	Sr, moderately-well sorted	planar-tabular forsets, non-graded	depositional surface is an angle of repose slip face on either a " longitudinal or transverse bar
7a-7c	gravel-sand	Sr, moderately well sorted sand	multiple trough cross-stratified sets	three dimensional dunes migrating in channels
8	gravel	Sr, well sorted	well-defined horizontal stratification	diffuse gravel sheets
9	sand	well sorted	massive to faintly laminated, non- graded	rapid deposition of sand from suspension during low velocity (waning) discharge
10	gravel-sand	well- sorted	thinly interbedded gravel-clay, reverse graded, massive to laminated and cross laminated	rapidly varying discharges i.e. deposits of ephemeral" "flash floods"
11	silt	well-sorted	massive, may contain rootlets	silts may be either fluvially deposited "suspension fall out" or aeolian loess
12	mud	well- sorted	laminated to cross-laminated, may be contorted and convoluted	suspension fallout in overbank or, shear zone of cohesive debris flow (facies 4)

Table 2. Ratios between the number of a-axis versus b-axis imbricated clasts for each facies

FACIES	A/B RATIO	COMMENTS
1	54/46	PROXIMAL TALUS (SECTION 1)
1	100/98	HYPERCONCENTRATED FLUID FLOW (SECTION 1)
4	46/50	COHESIVE, VISCOUS DEBRIS FLOW (SECTION 6)
2	37/63	MASSIVE BARCORE (FACIES 2) (SECTION 9)
2	38/62	MASSIVE FACIES 2 GRAVELS (SECTION 3)
3	37/61	MASSIVE FACIES 3 GRAVELS (SECTION 6)
2	28/72	CRUDE HORIZONTAL STRATIFICATION (SECTION 3)
2	30/7O	CRUDE HORIZONTAL STRATIFICATION (SECTION 8)
2	29/71	CRUDE HORIZONTAL STRATIFICATION (SECTION 8)
5	26/74	EPSILON CROSS-STRATIFICATION (SECTION 5)
5	17/83	EPSILON CROSS-STRATIFICATION (SECTION 7)
8	24/75	HORIZONTALLY STRATIFICATION (SECTION 5)
8	19/81	HORIZONTALLY STRAT. AT TOP OF SECTION 8
8	21/79	UPPERMOST HORIZONTALLY STRAT. AT SECTION 3

Beds of facies 1 found in the most proximal setting at Section 1 in the Miller Creek valley show the highest ratio of a- to b-axis imbricated clasts. Slightly smaller ratios, but with still high numbers of a-axis imbricate clasts are found in facies 4 . Beds of facies 2 which are in erosional contact with the underlying bedrock have a ratio of a- to b-axis imbrication which is consistantly > 1:3, which is greater than the imbrication ratio for (permafrost) as are most Quaternary sediments within the Yukon. Beds of the low-angle cross-stratified facies 5 and well-bedded, horizontally stratified gravels of facies 8 have a- to b-axis imbrication ratios of approximately 1:5.

(permafrost) as are most Quaternary sediments within the Yukon. Massive lenses or wedges of ice are especially prevalent where silt or organic-rich muds are predominant (Plate 1). This is a diagenetic feature and is not used to distinguish facies.

A. FACIES DESCRIPTIONS

Eight gravel facies containing between 55 % to 75 % gravel account for 70 % of the 500 measured beds and over 75 % of the 250 m of vertically mapped section. Other facies include sand, silt and mud types which account for 30 % of the measured beds, but only 25 % of the total vertical section.

FACIES 1. ANGULAR, CLAST-SUPPORTED MASSIVE GRAVEL.

This angular, clast-supported gravel which has a muddy matrix is massive and ungraded or normally graded. Within the study area it comprises 1 % of the measured beds. Beds of this facies are the coarsest (D 10 = 18.5), (MX is greater than 100.0) and the thickest (TH = 3.0). Examples of massive facies 1 beds are found at Section 1 in the Miller Creek valley (Plates 2 - 5).

Grain-size analyses show that this facies is a poorly-sorted, boulder-cobble size gravel with abundant mud matrix (up to 25 %) (see Appendix B). Beds are massive, apart from the less common

discontinuous intrastratified sands (Plate 2). Many "megaclasts" (clasts > 60 cm in a-axis length), which occur at the base or within the lowermost meter of the thickest beds, have an a-axis imbricate, a-axis flow-parallel orientation (Plate 3). Clast imbrications for these beds are 50 % (out of 300 counts) a-axis imbricate, 50 % b-axis imbricate (Table 2). Fabric analysis of cobbles within beds found on valley slopes indicates a transport direction towards the valley axis (Table 8), (see Appendix C). For beds (usually 1.0 - 5.0 m thick) on valley walls it is difficult to draw a contact between the base of the bed and the underlying deeply weathered graphitic-carbonaceous schist bedrock. At the bedrock contact the transition zone between gravel and competent bedrock is thinner (0.5 - 1.0 m) but still not sharp. At Section 1 in the Miller Creek valley there are steeply dipping a-axis imbricate clasts (Plates 4 and 5), in which the preferred orientation is downslope and perpendicular to the valley axis. Clast lithologies of this facies are dominated by locally-derived muscovite quartz schist, vein quartz and graphitic and carbonaceous quartz schists (Table 7)(see Appendix E).

FACIES 2. MASSIVE TO NORMALLY GRADED AND CRUDELY STRATIFIED GRAVEL

This is a clast-supported, sand-matrix gravel which is massive to crudely stratified. Most crudely stratified beds are ungraded. Beds of this facies are the most abundant (20 % of measured beds), are the second coarsest (D = 16.3) (MX = 38.2) and the thickest (TH = 0.75).

Examples can be found at the base of all sections except Section 1 in the Miller Creek valley (Figure 2). The best examples of these massive gravels occur at Sections 4, 5 and 6 (Figures A, B and C) and crudely stratified beds at Section 3 in the Sixtymile River valley (Plate 6).

Beds of this facies are clast-supported, subangular to subrounded gravels which are matrix-filled. They are massive or contain crude stratification defined by the presence of openwork pockets or, less commonly, by changes in gravel texture and grain size. Grain-size analysis (Appendix B) indicates that the framework is dominated by boulders and cobbles and a sandy matrix with little or no mud. Imbrication measurements show an increase in b-axis imbrication patterns in the crudely stratified beds (72 % b-axis imbricate) over massive beds (62 % b-axis imbricate) (Table 2). Fabric analysis (Appendix C) indicates a flow transport direction parallel to the valley. At 95 % of the sections this facies was observed in erosional contact with bedrock; basal contacts with other sediments were often deeply scoured. There is a wide variety of rock types (Table 7) that include both Carmacks Volcanics (andesite and conglomerates) and Nasina Series schists derived from the underlying bedrock. Other rock types apparent in clast lithology do not outcrop locally in the study area, and have therefore been transported > 15 km.

FACIES 3. SCOUR-FILL CROSS-STRATIFIED GRAVEL.

This is a clast-supported, graded-stratified gravel which is characterised by a concave-up scoured surface. Facies three accounts for 3.5 % of the beds, is the third-coarsest (D = 15.8), (MX = 21.8) and the third thickest (TH = 0.60). Good examples of these beds are found at Sections 6 in the Sixtymile River valley (Figures 2 and C) (Plate 7).

Beds of this facies are comprised of subrounded gravels which are infilled with a sand-size matrix (Appendix B). This facies is characterised by a scoured and channel-shaped basal contact marked by clast size changes. Most beds are massive boulder gravel that are normally graded, which become finer-grained and crudely stratified laterally (along strike). The average lateral continuity in section for beds of this faces is 3.0 - 4.0 m. The basal contacts of some beds are marked by a thin (2 - 3 cm thick) mud-draped, fining-upward sequence. Two beds are partially interbedded with wood debris and silt . Clast fabrics are 37 % (out of 100 counts) a-axis imbricate, 63 % b-axis imbricate (Table 2) and indicate a flow transport direction parallel to the valley (see Appendix C). Clast lithologies are similar to those of facies 2 (Table 7).

FACIES 4. MASSIVE TO CRUDELY STRATIFIED-INVERSELY GRADED GRAVEL

These beds are composed of massive or crudely stratifed and inversely graded gravels which have a mud-size matrix. Facies four beds account for 6.5 % of the measured beds and, as in most of the gravelly facies, the mean and maximum clast sizes (D = 12.0) and (MX = 16.2) correlate closely with bed thickness (TH = 0.60). Typical beds of this facies are found at Section 5 (Figures 2 and B), (Plate 8)

Stratification and mud-matrix support is best defined at the base of beds by convoluted and wavy stringers of matrix-supported pebbles. Typically beds are inversely coarse-tailed graded: horizontal stringers of matrix-supported pebbles grade upward to massive clast-supported cobble gravel or beds may be inversely graded over the upper 10 cm. Grain-size analysis (Appendix B) indicates the composition of the pebble stringers averages 60 % pebble gravel, 15 % sand-sized wood fragments and 25 % mud (of which about1/5 is organic material).

The ratio of a- to b-axis imbricated clasts is nearly random with 46 % of the clasts (out of 100 counts) a-axis imbricate, 54 % b-axis imbricate (Table 2). Fabric analysis indicates a tendency for the plane of the a- and b-axis to be horizontal and an a-axis imbrication up the local paleoslope (Table 8). Basal contacts are flat to irregular. In vertical sections these gravels are laterally continuous, stacked sheets. Commonly the lowest bed in a sequence is the thickest and contains the

largest wood fragments. Beds of this facies are composed entirely of andesitic lapilli tuff and basalt (Table 7). Beds at Section 7 in the Sixtymile River valley (Figure 2) contain a rich assemblage of broken, disarticulated Pleistocene mammal remains including: Equus, Mammuthus, Camelops hesternus, Ovibos moschatus, Rangifer, Ovis, and Panthera (Harrington, pers. comm. 1985) (Plate 9).

FACIES 5. LOW-ANGLE CROSS-STRATIFIED GRAVEL.

In this facies, single and multiple cross-beds at angles from 15 degrees in the upper part, and with gradational contacts at 2 to 5 degrees near the base are found in moderately well sorted, clast-supported gravels. The clasts are subrounded and dominantly cobble-sized (D = 17.0), less commonly boulder-sized (MX = 29.8). Although there are only six beds (less than 1 % of the total), individual beds are thick (TH = 2.5) and laterally persistent, generally traceable along strike from 12.0 - 20.0 m. Beds average 1.5 m in height. Individual sets averaged 7.1 m in length, and 10 cm in thickness. Examples of thick and laterally persistent beds are found at Sections 4 and Section 7 in the Sixtymile River valley (Figures 2, A) (Plate 10).

Individual sets are defined by couplets composed of alternating thick (10 -15 cm) coarse sand matrix-filled gravels and thinner (5 - 10 cm thick) openwork gravels. Grain-size analysis (Appendix **B**) indicates the matrix-filled beds consist of 75 % gravel and 10 % coarse sand matrix. Clast orientations are 21 % (out of 200 counts) a-axis imbricate, 79 % b-axis imbricate (Table 2). Clast-fabric analysis suggests a flow transport direction parallel to the valley (Table 8). Most basal contacts are flat and/or non-erosional. Clast lithologies are similar to facies 2 (Table 7).

FACIES 6. PLANAR CROSS-STRATIFIED SANDY GRAVEL AND SAND.

Beds of this facies contain planar-tabular foresets in both moderately-well sorted, sandy-pebble gravel and coarse sands (Plate 11). Beds of this facies account for 12 % of the measured beds. The framework is dominated by cobble-size clasts (D =10.5), (MX = 23.4). The beds are moderately thick (TH = 0.25). The grain-size distribution (Appendix B) indicates a gradation between gravel and pebbly coarse sands. However, there are too few planar cross-stratified beds (only 3), composed entirely of sand to justify a separate facies.

In the coarser grain-sized beds, planar tabular cross-stratification was defined by angle-of-repose foresets of poorly-sorted openwork gravel alternating with finer grained, matrix-filled gravels, which have a sharp angular contact with the bed below (Plate 11). Rare multiple sets occur. Sandy pebble-gravel beds average 20 cm in height and have flat bases. Single cross-sets average 7 cm in thickness, and are generally traceable laterally along strike over 3.0 m. Planar-tabular foresets also occur in pebbly coarse sands where individual sets are marked by thin (2 - 3 cm thick) alternations between granule-sized gravel and thicker coarse sand.

FACIES 7. TROUGH CROSS-STRATIFIED GRAVEL AND SAND.

Facies seven beds comprise 13 % of the beds measured. In contrast to the intermediate bed thickness (TH = 0.43), this is the finest-grained gravel facies (D = 7.1), (MX = 17.4). Best examples are found at Sections 4, 5, and 6 in the Sixtymile River valley (Figures A, B and C).

Beds of this facies are comprised of multiple sets of large-scale trough cross-stratification. They were mapped in sediment of all grain sizes between small-pebble gravel and medium-grained sand (Appendix B). Beds of this facies have been divided into subfacies based on the grain-size distribution. Best examples of trough cross-stratified gravels are found at Sections 4, pebbly sands at Section 5 and medium-grained sands at Section 6 in the Sixtymile River valley. Grain-size analysis of pooled data for all beds indicates a composition of 45 % gravel and 50 % well-sorted medium-grained sand. Most beds are ungraded with only a few (10 %) being normally graded.

SUBFACIES 7-a TROUGH CROSS-STRATIFIED GRAVEL.

Ten beds of this facies occur at Section 5 in the Sixtymile River valley (Figures 2 and B) and are characterised by multiple sets of trough cross-stratification in pebble gravels (Plate 12). An average grain size distribution is 65 % gravel with a maximum a-axis length of 7 cm and 15

% coarse to medium-grained sand matrix (Appendix B). Outlines of individual sets (averaging 7 - 11 cm thick) were defined by alternation between openwork and matrix-filled textures, grain-size variations and clast orientations. Sets were one to two meters in length and less than 20 cm in height. Beds are laterally continuous for 1.5 to 3.5 m. The contact between beds is an erosional trough.

SUBFACIES 7-b TROUGH CROSS-STRATIFIED PEBBLY SAND.

Beds of this facies are composed of moderately-well sorted coarse and medium grain-sized sands containing up to 25 % pebble gravel (Appendix B), and account for 2.5 % of the total 500 beds measured. A typical example can be found at Section 5 in the Sixtymile River valley (Plate 13). A mean bed thickness of TH = 0.33 is intermediate between subfacies 7a and 7c. Statistical measurements indicate the mean set thickness is 16 cm, and lateral extent of individual sets is less than one meter. Beds were mapped laterally over 5.0 m along section. These beds have scoured, concave-up basal contacts and upper surfaces which are sharply erosional.

SUBFACIES 7-c TROUGH CROSS-STRATIFIED SAND.

Beds of this subfacies are the most abundant of the three subfacies and account for 7 % of the measured beds, but have the lowest mean thickness (TH = 0.30). Best examples of this facies in medium-grained

sands (Plate 14, also see Appendix B) are beds at Section 6 and 6A in the Sixtymile River valley where average set thickness ranges between 5 - 7 cm. Basal contacts are erosional and distinctly irregular. Beds composed of sands are thinner (30 cm) than beds containing gravel, but are laterally continuous for 5.0 to 10.0 m along strike.

FACIES 8. HORIZONTALLY STRATIFIED GRAVEL.

Beds of this facies contain well-defined horizontal stratification in pebble and cobble gravel and account for 17 % of the measured beds. The mean clast size is relatively small (D = 13.0), but the large maximum clast size (MX = 30.2) indicates the presence of some large boulders. Beds are matrix-filled or openwork. Those beds which are matrix-filled are thicker (TH = 0.35) than the openwork beds (TH = 0.20). Excellent examples are found at the top of Section 4 in the Sixtymile River valley (Figure 2, Plate 14).

Beds of this facies are moderately-well sorted, clast-supported gravels which exhibit well-defined horizontal stratification in which horizontal sets are marked by a rhythmic alternation of cobble layers with finer-grained pebble-sized gravel. In some beds (23 %) stratification consists of alternating sand matrix-filled gravel and openwork gravel. Grain-size analysis (Appendix B) indicates the predominance of framework gravel clasts (mean 65 %) with 25 % coarse to fine-grained sand. Clast-fabric analysis indicates a flow transport

direction parallel to the valley axis. Clast imbrication patterns are 79 % (out of 400 counts) b-axis imbricate, 21 % a-axis imbricate. The basal contacts are flat. Clast lithologies are similar to facies 2 (Table 7).

FACIES 9. MASSIVE TO LAMINATED/CONVOLUTED SAND.

Beds of this facies are composed of well-sorted, silty, fine-grained sands (Appendix B) which are massive to faintly laminated or convoluted. They account for 5 % of the measured beds. Good examples of the thickest beds (TH = 0.12) are found at Section 3 in the Miller Creek valley and Section 8 in the Glacier Creek valley (Figure 2, Plate 15).

Most beds occur as 1.0 m to 20 cm thick, laterally extensive sheets which are interstratified with massive gravels. Internal structures are limited to faint parallel laminations, although locally in thick beds of this facies, convoluted internal structures can be related to loading of the upper contact. The basal contact is often flat and unscoured.

FACIES 10. THINLY INTERBEDDED GRAVEL, SAND, SILT AND CLAY.

This facies includes thinly interbedded gravel, sand, silt and clay which are massive, laminated and cross-laminated. Thin (TH = 0.05) facies ten beds account for 6.5 % of those measured, and therefore account for only 2.5 % of the measured vertical section. The best

examples are found at Section 3 in the Miller Creek valley (Figure 2, Plate 16).

Beds of this facies are brown, rust, or steel-grey pebble-gravels, well-sorted coarse to fine-grained sands, silts and clays which are massive, laminated or cross-laminated. This facies may be distinctly reverse graded (30 % of beds) from clay to granule gravel (Appendix B). These reverse graded beds are usually structureless and pinch and swell rapidly along strike. Other beds which are normally graded commonly show ripple cross-lamination or contain faint parallel laminations. Ungraded beds are rare. The basal contacts are irregular surfaces which drape the microtopography at the top of the underlying gravelly bed. Individual sets are small (only a few centimeters in height), and discontinuous as they pinch and swell laterally. In comparison, a few thick beds were mapped laterally over 75.0 m along strike.

FACIES 11. MASSIVE TO LAMINATED AND CONVOLUTED SILT.

This facies is composed of silts which are invariably brown, massive, and well-sorted (Appendix B), and which account for 7 % of the measured section. Descriptions of this facies were limited by poor exposure due to extensive development of massive ice wedges. (Plate 1). Good examples include those at Sections 3 and 8 and Section 7 (Figure 2, Plate 17)

Silt beds are distinctly separated into two classes according to bed thickness. The first consists of massive brown silt averaging 4 cm in thickness. The second consists of four beds at Section 7, which average 95 cm. These thicker silts are massive, but contain numerous fine rootlets, and locally burrows and middens (fossilised nests) of arctic ground squirrels (D. Harington, personal communication, 1984)

FACIES 12. MUD.

These are thinly laminated, contorted or convoluted beds composed of fine silt and mud (Appendix B). Beds of this thick facies (TH = 0.70) account for nearly 10 % of the measured beds and a substantial amount (7.5 %) of the vertical section. The best exposures are at Section 6 in the Sixtymile River valley (Figure 2, Plate 18).

Most beds are thinly laminated, contorted or convoluted and organic-rich (some beds contain up to 10 % sand-size organic material). Beds of this facies, which occur above the coarse fluvial gravels at Sections 6 and 7 in the Sixtymile River valley (Figure 2), have a "sheared appearance" and are intensely deformed. These convoluted beds may contain massive fragments of tree trunks, 4 to 5 cm in diameter and 2.0 - 4.0 m long. The wood is most common in the lowermost bed of a stacked sequence of interbedded facies 12 and facies 4 beds. Pods of clast-supported, matrix-filled massive cobble gravel (20 cm high by 150

cm long) may occur as intraclasts floating within the muds (Plate 19). However, not all beds show this distinct sedimentary structure. For example, the one bed at Section 2 is reverse graded and the thick beds of this facies capping Sections 3 in the Miller Creek valley and Section 5 in the Sixtymile River valley (Figure 2) are massive.

B. FACIES INTERPRETATIONS

For each facies recognized within the study area the observed sedimentary structures and textures are used to interpret the flow type, mechanism of grain support and mode of deposition (Table 3).

FACIES 1 ANGULAR, CLAST SUPPORTED MASSIVE GRAVEL.

These are clast-supported, poorly-sorted angular gravels which appear texurally similar to primary weathered bedrock. Characteristic features are the massive nature of beds except for thin interbedded coarse sands, a variable clast fabric including mega-clasts which are a-axis imbricate upvalley parallel to flow, and poorly organized fabrics in the finer fractions with both a- and b- axis imbricate clasts orientated downslope perpendicular to the valley-trend. There is a strongly bimodal distribution with a matrix of coarse-grained poorly-sorted sands and up to 10% mud.

These features are interpreted to represent deposition of gravel as proximal talus or, as sediment-charged flood-flow deposits similar to the "hyperconcentrated flood flows" of Smith (1986). Massive and structureless beds on steep valley walls which show both a- and b-axis imbrication downslope, perpendicular to the valley trend, are interpreted

Table 3 . Flow type, mechanism of grain support and mode of deposition of sediments for each facies.

FACIES	FLOW TYPE	SUPPORT	MODE OF DEPOSITION
1. Angular, clast supported, mud-matrix filled, with clasts a-and b-axis valley normal and a-axis flow parallel	Slow creep downslope or partially turbulent flood flow	Turbulence, grain dispersive pressure, hyperconcentrated	Rapid grain-by-grain aggradation from both buoyancy, suspension and traction
2. Subangular, clast supported, sand matrix gravels,massive-normally graded-stratified.	Fully turbulent	Turbulence	Grain-by-grain aggradation of gravel followed by suspension settling of sand
3. Trough-shaped scoured surface overlain by massive to graded-stratified gravel	Variable, mostly fully turbulent, may be minor cohesive debris-flow deposits (facies 4)	Mostly turbulence, some suspension settling or laminar shearing	Grain-by-grain aggradation of gravel and settling of sand.
4. Angular, mud-matrix supported, inversely graded	Laminar at time of deposition but may be turbulent on steep slopes	Matrix strength, grain dispersive pressure, buoyancy	Rapid freezing or *en masse* deposition
5,6,7. Large-scale,trough and planar-tabular cross-stratification.	Transport is by turbulent flow but grains avalanche down foreset. (upper flow regime)	Turbulence and grain dispersive pressure	Grain-by-grain aggradation followed by mass emplacement of avalanching gravel
8. Horizontally stratified gravel with a sand matrix	Fully turbulent (upper flow regime)	Turbulence	Grain-by-grain aggradation from traction followed by suspension settling of sand.
9,10. Massive to laminated and convoluted sands and interbedded sands, silt, and clays.	Fully turbulent to standing quiet water (upper and lower flow regime)	Turbulence	Grain-by-grain aggradation from traction and suspension
11. Massive silts	Turbulent? (lower flow regime)	Turbulence	deposition from suspension
12. Thinly laminated to convoluted organic rich muds.	Laminar flow or quiet water (lower flow regime)	Matrix strength and dispersive pressure	deposition from suspension or rapid freezing

as proximal talus. The absence of any clear sedimentary structures, the clast angularity, and the clast imbrication downslope suggest that the mud matrix is a product of weathering and soil forming processes and is not genetically related to transportation of the gravel. A 1:1 ratio between the number of a- and b-axis imbricate clasts (Table 2) is a function of both the clast shape (angular and blocky) and the high degree of clast interaction during slow creep which restricted the development of a preferred fabric.

Massive beds are characterised by the presence of a-axis imbricate mega-clasts in finer-grained massive gravels, a muddy matrix and discontinuous intrastratified sands. These massive beds are interpreted as gravels deposited by hyperconcentrated flood flows intermediate in nature between viscous or cohesive debris-flows and normal fluid flow. This type of deposit is distinguished from cohesive and viscous debris-flow deposits by the lack of both matrix-support and inverse grading. This facies differs from normal stream-flow deposits by the presence of very poorly-sorted, coarse-sand matrix, clasts with a-axis parallel to flow, and both a- and b-axis downslope imbrications.

Flow is interpreted to be partially turbulent, with smaller eddies being damped by the high sediment concentrations. The grain-support mechanism involve normal fluvial-flow turbulence, but the high concentration of suspended sediment (indicated by the coarse-sand

matrix) indicates that grain dispersive pressures and buoyancy may have been important factors in the support of the gravel clasts during transport.

Development of a preferred gravel fabric suggests that individual clasts were relatively unhindered by interactions during deposition and therefore were not deposited *en mass*.e Instead, depostion was grain-by-grain from both suspension and traction. High ratios of a-axis to b-axis imbricate clasts (nearly 1:1) is a function of both clast shape and mode of deposition. The presence of scattered, vertical cobbles and small boulders may reflect post-depositional cryoturbation. Discontinuously intrastratified sands found within the gravels are interpreted as the result of fully turbulent fluid flows, which followed the rapid and high energy sediment-laden flows which deposited most of the gravel. Thus these intrastratified sands represent secondary reworking by the later-stage turbulent fluid flows.

FACIES 2 MASSIVE TO NORMALLY GRADED, STRATIFIED GRAVEL .

This facies is a massive to crudely-stratified, sand-matrix gravel, which is clast-supported, moderately-well bedded, commonly imbricate and rarely normally graded. The dominance of a-axis flow-transverse and b-axis imbricate upstream clasts indicates the clasts were deposited from tractional bedload (Johannsson, 1965). During the upper flow regime necessary to transport these coarse gravels the sand was

supported by turbulence in the flow. The mode of deposition was a grain-by-grain aggradation of gravel. Sand was held in suspension until the flow velocities waned.

When beds of this facies occur at or near the base of a section in contact with bedrock, they are interpreted to represent winnowed gravel lags transported in confined channels during only the strongest flood-flows. The upward transition from massive to crude horizontal stratification is suggestive of vertical aggradation and formation of diffuse gravel sheets under decreasing flow strength and decreased bedload transport as suggested by Hein and Walker (1977). Slight variations in textures and structures were noted between these lag gravels at the base of most sections and those in the middle to upper parts of Sections 2 and 3 in the Miller Creek valley and Section 8 in the Glacier Creek valley (Figure 2). Variations in these latter beds include an increased percentage of a-axis imbrication, more clearly-defined bed contacts, a smaller mean and maximum grain size, a coarser sand-matrix and the greater prevalence of openwork pockets. These depositional units are interpreted as distal hyperconcentrated flood flows.

Similar to the muddy matrix in facies 1, the coarse-sand matrix in facies 2 suggests hyperconcentrated , partially viscous, flood-flow deposits (Smith, 1986). Clasts fabrics only arise when the clasts have the freedom and the time to become orientated to the flow. Low ratios

of b- to a-axis imbrication in beds at Section 3 in the Miller Creek valley and Section 8 in the Glacier Creek valley imply that clast mobility may have been hindered by the high sediment and flow discharges or clast shape. The absence of cross-stratification in this facies suggests that high sediment and flow discharges may have suppressed the development of foreset margins. Smith's (1985) "rule of thumb" for the formation of slip-face foreset margins suggests that foreset margins develop only if the flow depth:grain size ratio is > 10. Based on the measurement of the mean maximum a-axis length of 22 cm, the maximum flow depths during the depositon of these gravels was < 2.2 m.

FACIES 3 SCOUR-AND-FILL CROSS-STRATIFIED GRAVEL.

This facies is characterized by a scoured, broadly U-shaped (concave-up), erosional basal contact which is interpreted to represent the outline of a scourhole or channel cut into pre-existing fluvial gravels during peak flow. Structures and textures of the fill above the erosional surfaces are highly variable and reflect different flow types, grain support mechanisms and modes of sediment deposition. This fill includes: (1) massive boulder-cobble gravel with a sand matrix, (2) boulder to cobble gravel which is normally graded, laterally fining or thinning, and discontinuously stratified, (3) inverse grading from organic-rich silts and muds to coarse gravel (in two cases containing matrix -supported cobbles), and (4) thin, mud-draped fining-up

sequences.

The transport of gravel as tractional bedload is indicated by the a-axis current-transverse, b-axis imbricate upstream boulders within the scoured channel. The well-sorted matrix is typical of fine sands carried in suspension during a fully-developed, turbulent, upper flow regime. The sand supported by turbulence, infiltrated into the bed when flow velocities waned (Harms et al. 1982). Therefore the mode of gravel deposition is a rapid grain-by-grain aggradation in the channel of tractional bedload. This is followed by deposition from suspension of the sand matrix during waning flow (Table 3).

Normally graded, laterally-fining and thinning pebble to boulder gravel fills, which are dominated by minor discontinuous stratification in the upper and outer margins, are interpreted to record the gradual rather than rapid abandonment and fill of the channels and scourholes. Abandonment of these channels during aggradation led to shallower, lower velocity flows. Except for the lower flow and sediment discharges, the grain support mechanisms and mode of deposition of this fill are similar to that of the massive channel-fill.

Those beds which are inversely graded from organic-rich silts and muds to coarse gravel represent the reoccupation of previously

abandoned channels and infilling of the channels under increasing flow. Structures and textures of these beds indicate a transition from lower flow regimes, dominated by deposition from suspension, to upper flow regimes, dominated by tractional bedload transport and grain-by-grain aggradation of tractional bedload during fully turbulent flow. However, special attention must be given in the field to documenting reverse-graded channel fills because the presence of isolated clasts in the mud (which are easy to miss) can indicate a cohesive, viscous debris flow (see facies 4), rather than tractional bedload of a fluvial channel. Thin, mud-draped, fining-upward sequences partially in-filling channels are common at Section 4 in the Sixtymile River valley (Figure 2, Figure A) and represent the final stages of channel abandonment, in which deposition of fining-upward sequences in the thin muds occured under shallow, low-flow regimes by tractional bedload transport of fine sands and deposition from suspension of silts and muds.

FACIES 4 . MUD-MATRIX SUPPORTED, INVERSELY GRADED GRAVEL.

This is a inversely graded gravel in which mud matrix-supported clasts are both a-and b-axis imbricate. Mud matrix-support and crude subhorizontal stratification of matrix-supported pebbles and small cobbles alternating with thinly laminated mud occur at the base of the beds.

Mud-matrix support of the clasts, inverse grading in a thin basal zone

and an a-axis flow parallel, a-axis imbricate up-slope pebble fabric suggest deposition of these gravels from cohesive, viscous debris flows (Schultz, 1984). Fluid properties of such flows are similar to viscous muddy debris flows described by Johnson (1963) in which a rigid plug of mud matrix-rich gravel moves downslope by laminar shearing over a basal zone of organic rich mud. Support of the clasts was provided by the strength of the mud-rich matrix, dispersive pressures resulting from clast interactions and buoyancy arising from displacement of both the mud and fluid. Thinly laminated, contorted and convoluted organic-rich mud of the basal shear zone is considered as a separate lithofacies (facies 12). Inverse grading over the upper 10 cm documented in one bed at Section 6 in the Sixtymile River valley (Figure 23d) suggests that the largest clasts sometimes rode on the upper surface of the flows as documented in observations of modern flows (Johnson,1963). Examination of the basal contacts indicates that there was little basal scouring during movement of the debris flow. However, the presence of broken and fractured tree limbs and trunks in the gravels indicates that the debris flow was a rapid and catastrophic event which destroyed any vegetation in its path. Since individual flows have non-erosive basal contacts, the bed thicknesses as measured in outcrops provides a minimum estimate of flow thickness of 0.70 m. This is a minimum value because during debris flow surging may occur which increases the thickness of the flow.

The lithologies of the cobbles in the angular gravels in this facies

indicate a local provenance restricted to andesite bedrock outcropping on the steep south-facing slopes between Sections 5 and 7 in the Sixtymile River valley. As mentioned in the description, in addition to the gravel clasts, there has been a large volume of bone recovered from exposures of this facies at Section 7 in the Sixtymile River valley (Figure 2, Plate 9). There is a wide range of species in the fossil assemblage, which includes carnivores (lion and bear) and large herbivores: sheep, moose, muskox, cariboo, horse (two species of ass), bison and mammoth (Harrington, pers. comm.,1985). Although extant communities of herbivores similar to this are unknown, it is unlikely that such a wide diversity of herbivourous mammals occupied the study area during the same part of the year. Therefore, these remains represent a death assemblage, possibly disarticulated bone lying on the surface, which was swept up as detritus and incorporated into the flow. The high concentration of bone fragments near the toe of the debris flow resting on the terrace gravels at Section 7 in the Sixtymile River valley may be related to the mechanism of mud-matrix, clast-support in debris flows. One possible method to enrich the debris flow in bone is the selective removal of the heavier rock clasts. Buoyancy of the clasts (Bagnold, 1954) or the efficiency of the kinetic sieving mechanism (Middleton, 1970) depends upon the density contrast between the clasts and the cohesive mud matrix. The bone may have been selectively transported because the density contrast between the bones and the mud is less than that between the mud and the andesite clasts derived from the underlying bedrock.

FACIES 5. LATERAL-ACCRETION CROSS-STRATIFIED GRAVEL.

This facies is characterized by large-scale, lateral accretion cross-beds (averaging 2.5 m in height and 15 m in lateral extent) which are inclined up to 15 degrees. The cross-beds are defined by rhythmic alternations of thick (10-15 cm thick), coarse sand, matrix-filled, pebble gravels and thinner (5-10 cm thick) and coarser openwork gravels. The clasts have one of the highest ratios of b- to a-axis imbrication (5/1) (Table 2). Most beds of this facies are restricted to the Sixtymile River alluvial plain and the adjacent terrace (Figure 2, Figure A).

These features bear a strong resemblance to lateral-accretion cross-stratifed beds recorded in sandy meandering river systems which were interpreted by Allen (1964) as the product of lateral accretion of a point bar. Similar cross-stratification in gravelly streams was noted by Jackson (1978). He suggested that clasts were transported as bedload across the upper portions of the bar surface under upper flow regimes (fully turbulent). The clast-support mechanism in this type of flow would be the typical tractional bedload movement of fluvial systems in which grains are supported by turbulence and aggradation takes place in a grain-by-grain fashion. Upon reaching the foreset margin of the bar, clasts then avalanched downwards along the slipface. This avalanching on the slipface of the bar occurred as a sudden mass

emplacement in which clast interactions and dispersive pressures were the major support mechanism. The avalanching of clasts is most likely responsible for the high ratio of a-axis imbricate clasts.

Stratification defined by the alternating matrix-filled and openwork pockets indicates fluctuations in sediment and flow discharge (Harms et al., 1982). In this facies, thin and coarse openwork gravels probably represent the higher periods of discharge during which a fine-grained matrix was held in suspension while avalanching of clasts down the slipface occurred regularly. This avalanching resulted in openwork pockets of inversely-graded, bottom set-gravels. During lower velocity flow, sand held in suspension infiltrated into the bed to form the matrix.

FACIES 6. PLANAR TABULAR CROSS-STRATIFIED GRAVEL.

These are moderately well-sorted gravels with a well-sorted sand matrix in which single beds with foresets with angular basal contacts are defined by alternation of matrix-filled and openwork gravel. These planar tabular cross-beds are interpreted as deposits formed during the downstream migration of high relief barforms with angle-of-repose foresets (Miall, 1973; Boothroyd and Nummendal, 1978) In the model for stratification proposed by Hein and Walker (1977), high-angle cross-stratification was associated with transverse and longitudinal bars with foresets. Regardless of the type of barform, a sufficient depth of channel is necessary in order that flow separation could

develop over the gravel bars (Boothroyd and Nummedal, 1978). Using N.D. Smith's (1985) "rule of thumb" for the formation of slip-face foreset margins, facies 6 gravels with an average grain size of 14.2 cm (maximum 23.4 cm) would imply flow depths were on the average >1.4 m (maximum 2.3 m). The low frequency of this facies (other than at Section 4 in the Sixtymile River valley) indicates that within the study area only rarely did flow approach the depths necessary for development of foreset margins.

FACIES 7. TROUGH CROSS-STRATIFIED SANDY GRAVEL AND SAND.

Beds of this facies are characterized by multiple sets of large-scale trough cross-stratified sands and small pebble gravels. The geometry of the low-angle troughs, the mean clast size, and overall set dimensions suggest deposition from fields of large-scale three-dimensional dunes. The three subfacies, based on grain size, reflect variations in flow and sediment discharge. The maximum clast size of subfacies 7a is approximately 7 cm. This is greater than the 5.4 cm suggested by Fahnestock and Bradley (1973) as the upper limit of clasts which could migrate as gravelly dunes. The trough cross-bedded, gravelly sands of subfacies 7b and coarse to medium sands of subfacies 7c would reflect lower flows and discharges (see discussion below).

SUBFACIES 7a. TROUGH CROSS-STRATIFIED GRAVEL.

In flood flows of 6,600 m^3/ sec. on the Knik river of Alaska Fahnestock and Bradley (1973) recorded the size diameter of clasts larger than 90% of the bed material as 5.5 cm. In this study the mean maximum a-axis length of the 10 largest clasts is 7 cm. The larger clast size is due to the prevalence of rod-shaped clasts. However, the migration of gravelly dunes with a clast size approaching 5-6 cm would require fully-developed turbulent flow in deep water. Some Facies 7 beds at Section 4 in the Sixtymile River valley are characterized by poorly-sorted pebble and cobble lags. An explanation for these beds may be the rapid depositon of poorly-sorted gravelly sand into small scour holes or pockets.

SUBFACIES 7b. TROUGH CROSS-STRATIFIED PEBBLY SAND.

This subfacies is comprised of pebbly sands in which pebbles occur as thin lags marking the scoured outlines between indiviual trough sets. Hydrodynamic interpretations of this facies suggest flows intermediate between that of facies 7a and 7b. General estimates of the flow depth and velocity can be extrapolated from bedform stability plots for coarse sand and gravel reported by Middleton and Southard (1984). These plots of flow depth versus flow velocity suggest that similar three dimensional dunes typically develop in flows of ~ 1 m depth at flow velocities of 0.75 - 2 m/sec.

SUBFACIES 7c. TROUGH CROSS-STRATIFIED SAND.

Well-sorted, trough cross-bedded sands are considered to reflect deposition from large-scale three dimensional ripples and dunes (Middleton and Southard, 1984). Well-developed, trough cross-bedded medium- to coarse-grained sands deposited in this manner are most common in the upper portions of Section 4 in the Sixtymile River valley (Figure 2). Based on data presented in bedform stability plots, (Blatt et al.,1980) suggested ripples of this size tend to be flattened at higher velocites. Those bedforms examined in the field had normal geometries, and based on the flow depths and velocities from reported flume studies (Middleton and Southard, 1984), it is suggested that most of these bedforms developed in shallow channels (e.g. 20 cm deep) with moderate flow velocities (e.g. 80 cm/sec.). A few cross-stratified sands show asymmetric trough or ripple formsets (e.g. the bed in Figure C at 33 -37 m). These tend to occur on the lee side of large gravel sheets and have basal contacts that dip steeply downstream. They are interpreted as a bar marginal sand similar to those sand wedges described by Rust (1972) as sand bodies formed on the downstream depositional bar slipfaces during low water stages.

FACIES 8. HORIZONTALLY STRATIFIED GRAVEL.

These are moderately well-sorted, clast-supported gravels with a

sand matrix, which are horizontally stratified. Stratification consists of sharply-bounded beds marked by differing clast sizes, sorting or fabric. Clasts are oriented dominantly a-axis flow transverse, b-axis imbricate upstream, which indicate a sediment transport direction parallel to the trend of the valley. These features are suggestive of vertical aggradation or stacking of successive gravel sheets on subhorizontal surfaces or the aggradation and progradation of low-relief longitudinal or diagonal bars. Flow during movement of these gravels would have been fully-developed turbulent fluid flow in which gravel clasts moved as tractional bedload. Finer-grained sands were held in suspension and infiltrated into the gravel only during lower flow.

Similar to facies 2, the absence of cross-stratification indicates that shallow flow depths inhibited the development of flow separation necessary for the formation of angle-of-repose slip faces on the margins of the gravel sheets. Again, using N.D. Smith's (1985) "rule of thumb" for the formation of slip-face foreset margins, facies 8 gravels with an average grain size of 13 cm (maximum 30 cm) would imply that flow depths were on the average <1.4 m (maximum 3.0 m). As in the model proposed by Harms et al. (1982) fluctuating or varying discharges are responsible for each layer. Openwork beds represent tractional bedload deposited under flow in which the sand was held entirely in suspension, and the thin sandy interbeds reflect suspension fall-out of the sands during waning discharge (Harms et al.,1982)

FACIES 9. MASSIVE TO LAMINATED AND CONVOLUTED SAND.

These are massive beds of well-sorted, silty, fine- to medium-grained sands interpreted to reflect rapid deposition of sand from supension or, in the case of laminated beds, lower velocity waning discharge within channels or on bartops. Experimental flumework reported by Middlton and Southard (1984) suggests that at most naturally-occurring mean flow velocities and depths, deposition of this size sediment results in laterally extensive massive sheets or beds. Extensive post-depositional loading of massive gravels was documented at Section 8 in the Glacier Creek valley where the upper surface of the massive silty sand bed was convoluted due to loading by deposition of the overlying gravels. This suggests rapid emplacement of the sands without sufficent time for compaction before subsequent burial.

FACIES 10. INTERBEDDED GRAVEL, SAND, SILT, AND CLAY.

These are thick, laterally extensive beds composed of gravel, sand, silt and clay, which show complex interbedding and a wide variety of sedimentary structures. The sedimentary structures and textures suggest the deposition of sediment under rapidly varying discharges that are characteristic of ephemeral flash-floods.

Deposition of up to 20 cm of thick clay units interbedded with the silts and sands required stagnant to very low flow with little or no

turbulence (possibly ephemeral ponds). In studies of proglacial outwash, faintly laminated fine silts are products of deposition from suspension in low flow in the overbank (Boothroyd and Nummedal, 1978). Higher velocities and discharges are indicated by thick and massive silts that reflect rapid deposition of suspended sediment without the development of tractional bedforms. Finally, distinctly inversely graded beds from silt → coarse sand → granule /gravel are evidence for increasing discharge under which increasingly coarser sediment underwent tractional bedload movement. In turn, the inversely graded beds are commonly overlain by the thick, massive clays which represent rapid decreases in flow and discharge and a return to slow rates of aggradation in standing water.

FACIES 11. SILT.

Similar to the massive silty-sand facies, massive well-sorted facies 11 silts represent rapid deposition of suspended sediment, but under slightly lower flow than facies 9. Laminations may be visible if the silt was deposited during waning flow. An eolian origin is suggested for thick beds exposed at Section 6 in the Sixtymile River valley, which are located several meters above the level of the terrace. Any original sedimentary structures were destroyed during formation of massive ground ice that cut through the section or, by growth of the extensive network of fine roots throughout the silt (Plates 1 and 17). The development of massive ground ice in thick vertical wedges is a typical

feature in silts when there are severe winter temperatures, but sufficently warm temperatures during the summer months to form a thin active layer (Pewe, 1983).

FACIES 12. MUD.

The fine grained mud of facies 12 occurs as either massive to faintly laminated or, highly contorted and convoluted beds. The massive muds are interpreted as being deposited from suspension on the fringes of the alluvial plain, perhaps in overbanks. The highly contorted and convoluted muds are sheared, finely laminated beds (~ 5 - 10 cm thick) from the basal zone of rapidly emplaced cohesive and viscous debris flows. Examples of fine-grained muds which filled abandoned channels or covered bar-tops are found at Sections 4, 5 and 6 in the Sixtymile River valley where they were preserved from erosion by burial under subsequent debris flows. Beds with convoluted laminations, inverse grading, fragments of shattered wood, intraclasts of massive clast-supported gravel and sharp non-erosional contacts are interpreted to have been deformed by laminar shearing, representing the basal sheared layers at the base of facies 4 debris flows.

CHAPTER VI. FACIES RELATIONSHIPS

In Chapter IV individual facies were interpreted as the product of processes active during sedimentation i.e. a flow type, mechanism of support and mode of deposition was suggested for each facies. However, in proposing an environmental interpretation for a facies, it is essential to discuss the facies in context with other facies. This context, or tendency of different facies to occur together is a facies "association", and these are crucial to interpretation of the depositional environment.

In this study, facies relationships were evaluated by three methods. Firstly, facies relationships were evaluated by a comparison of the relative abundances of facies at the different sections. A measure such as this indicates the broad trends in the mode of sediment transport and deposition. The second method of evaluation was to test the vertical facies sequences for cyclicity by a Markov chain analysis. The third method of examining facies relationships is to map the lateral facies relationships in the outcrop. Most often in sedimentology the lateral associations are interpreted by using Walther's *Law of Facies* (1894). Here a vertical succession of facies (either that measured directly from the outcrop or derived from a facies relationship diagram), when placed horizontal, is interpreted as representing the original association of facies and, thus, reflecting the lateral association between environments (Reading, 1978). Due to good lateral continuity of outcrops

in the study area it was possible to describe some of the lateral facies associations and compare these associations to those arrived at by Markov chain analysis.

A. RELATIVE FACIES PERCENTAGES

There are significant differences in the abundance of facies between sections (Table 4), and it is suggested that these facies abundances were controlled by differing modes of transport and deposition in four different types of alluvial settings. The first types of alluvial settings include: valley-fill, terrace and alluvial plain sites, all of which are dominated by gravels and sands with typical fluvial features. The valley-wall alluvium is a complicated mixture of deposits in which inferred sediment-gravity flows are most important.

Valley-fill alluvium at Sections 1, 2, 3 in the Miller Creek valley and Section 5 in the Sixtymile River valley is comprised of poorly-sorted, massive to crudely or well-stratified gravels, (facies 1, 2, and 8) and shows little evidence of cross-stratification (i.e. low relative abundances of either facies 3, 6 or 7). The relative proportion of finest-grained facies deposited in a fluvial setting (facies 9, 10, 11) reaches a maximum of 35 % at Section 3 in the Miller Creek valley. In comparison, the terrace gravels at Sections 6, 10 and 7 in the Sixtymile River valley are dominantly cross-stratifed (facies 3 and 7)

Table 4. Relative percentage of facies at each section (columns sum to 100 %)

	SECTION								
FACIES	1	2	3	4	5	6	10	7	8
1	100	-	-	-	-	-	-	-	-
2	-	46	29	20	27	13	8	11	35
3	-	8	2	9	16	22	4	-	1
4	-	13	1	-	-	-	-	18	-
5	-	-	-	11	-	-	-	2	-
6	-	-	5	2	2	3	-	3	8
7	-	17	2	47	18	19	24	5	13
8	-	13	20	6	13	16	20	13	29
9	-	-	14	-	6	-	12	18	2
10	-	-	13	-	6	-	4	2	2
11	-	-	7	-	2	-	12	15	9
12	-	4	5	-	9	27	16	11	-

or horizontally stratified (facies 8). The relative percentage of fine-grained beds is also higher (> 30 % of beds at Section 10). In the "Sixtymile River alluvial plain gravels" at Section 4 the most common facies are the cross-stratified sands and gravels of facies 3, 5 and 7, with no finer-grained silts or muds.

In each of these three settings the flow type was either fully or partially turbulent, and aggradation is essentially grain-by-grain. The differences in relative abundance of massive, crude or horizontal stratification and cross-stratification are attributed to slight differences in flow depth, channel patterns, and effective reworking in the three different fluvial environments. Gravelly facies 1 and 4, and finer-grained facies 11 and 12 are prevalent on the steeper slopes at Section 1 in the Miller Creek valley, on the surface of the alluvial fan near the valley walls, and especially in the thick sequences overlying gravels of the terrace. The mode of transport and aggradation of these facies suggest a "non-fluvial origin". They represent either colluvial, debris-flow or aeolian modes of transport.

Within the sequences of valley-fill alluvium, there are proximal to distal trends which are characterized by increased sorting and rounding, and decreases in maximum and mean grain sizes. From proximal to distal settings, facies transitions are massive → crudely stratified → horizontally stratified gravel. In addition, there is a down-valley increase in the percentage of cross-stratified facies (facies 3 and 7)

suggestive of bar development. Proximal valley-fill alluvium at Section 1 in the Miller Creek valley is dominated by massive and disorganized gravels (facies 1); while at intermediate valley sites (Section 2) massive or broadly trough cross-stratified gravels and horizontally stratified gravel (facies 2, 3, and 8) with trough cross-stratified pebble gravels (facies 7) are more abundant. Distal downvalley sites near the valley-axis are mostly massive to crudely stratified gravel and horizontally stratified gravel. Massive to laminated sands and coarsening upward sequences from clay — gravel (facies 10) also occur. The most distal downvalley site (Section 5 in the Sixtymile River valley) shows predominantly alternating beds of crude to well-stratified and trough cross-bedded gravels (Facies 2, 8 and 3) and trough cross-bedded pebbly sand and massive sand (facies 7 and 9).

B. MARKOV CHAIN ANALYSIS AND VERTICAL FACIES ASSOCIATIONS

1) METHODS

Miall (1973) suggested that Markov chain analysis, a simple statistical method for detecting repetition, can be used to examine cyclicity in vertical sequences of sedimentary facies. In this study transition count matrices (tally matrices) were tabulated for the upward facies transitions observed in the measured sections. The

method of counting transitions corresponds to the embedded method of Krumbein & Darcy (1969) in which there are no transitions between beds of the same facies and the principal diagonal of the matrix contains zeros. The second matrix (not shown) is a probability matrix, which represents the random probability of the given transitions between facies. This matrix was calculated following the methods of Harper (1984a, 1984b), Carr (1982) and Powers and Easterling (1982) based on a proportional fitting technique. The last matrix (not shown) is a difference matrix, which shows the difference between the transition matrix and the random probability matrix. Positive values in this matrix represent transitions which occur at greater than random probability. The principal facies relationships were summarized by a facies relationship diagram in which positive values from the difference matrix indicate the principal transitions between facies.

A major constraint of the embedded technique of Markov chain analysis is that facies transitions are limited to those between different facies. Repetitive transitions between the same facies are excluded in this study (e.g. the stacking of multiple facies 2 or 8 beds is a common facies association, but it has been excluded from the Markov chain analysis).

Cyclicity of the vertical facies sequences was tested using three different tally matrices (Figures 6, 7 and 8). The first tally matrix

	2	3	4	6	7	8	9	10	11	12	
2	X	2	2	3	3	18	3	2	1	2	36
3	3	X	-	-	-	-	1	-	-	1	5
4	3	-	X	-	-	-	-	-	3	9	15
6	-	3	-	X	-	1	-	1	-	-	5
7	5	1	-	-	X	3	-	1	-	7	17
8	9	3	1	1	9	X	5	5	7	2	42
9	5	-	-	-	-	3	X	3	2	-	13
10	2	-	1	1	-	4	2	X	2	2	14
11	2	-	3	-	-	7	3	4	X	8	27
12	-	-	16	-	-	2	4	2	6	X	30

Σ 204

Figure 6. Tally matrix for all sections pooled together excluding Sections 1 and 4. This matrix shows transitions between all facies except facies 1 and 5.

	2	3	4	6	7	8	9	10	11	12	
2	x	2	2	1	1	13	3	2	3	-	27
3	2	x	-	-	-	-	-	-	-	-	2
4	1	-	x	-	-	-	-	-	-	-	1
6	-	1	-	x	-	-	-	-	-	-	1
7	3	-	-	-	x	1	-	-	-	-	4
8	6	3	1	-	2	x	6	2	6	1	27
9	5	-	-	-	-	1	x	3	-	-	9
10	2	-	-	-	-	2	1	x	1	2	8
11	3	-	-	-	-	6	-	-	-	1	10
12	-	-	1	-	1	1	-	1	-	x	4
										Σ	93

Figure 7. Tally matrix for sections of valley-fill alluvium, including Sections 2,3,5 and 8. Excluded from the matrix are facies 1 and 5

	2	3	4	6	7	8	9	10	11	12	
2	X	-	1	2	2	5	-	-	1	2	13
3	1	X	-	-	-	-	-	-	-	1	2
4	2	-	X	-	-	-	-	-	3	17	22
6	-	1	-	X	-	1	-	1	-	-	3
7	2	1	-	-	X	1	-	1	1	7	13
8	2	-	-	1	7	X	1	3	1	1	16
9	-	-	-	-	-	2	X	-	2	-	4
10	-	-	1	1	2	1	-	X	1	-	6
11	-	-	3	-	-	1	3	1	X	7	15
12	-	-	14	-	1	1	4	1	6	X	27
											Σ 117

Figure 8 Tally matrix for upward transition of "Sixtymile River terrace" gravels.. Includes facies transitions from Sections 6, 7 and 10.

was based on pooled data for all the measured vertical sequences and represents over 200 transitions between the ten most common facies in the study area. Based on geomorphic evidence "paleo-Miller Creek and Glacier Creek data were pooled from the valley-fill alluvium" at Section 2, 3, 5 and 8 and separated from the thinner gravels on the "Sixtymile River terrace" at Sections 6, 7 and 10. Therefore, transitions in sequences of valley-fill and terrace alluvium were treated separately (Figures 7 and 8). From each of the three difference matrices, facies relationship diagrams representing the principal transitions between facies were constructed (Figures 9,10, and11).

2) GENERAL FACIES ASSOCIATIONS

All three facies relationship diagrams show three major facies associations which include: (1) a coarse-grained facies association which may include facies 2, 3, 6, 8 , (2) fine-grained facies association which may include facies 7, 9, 10, 11 and 12 and (3) a repetitive fine-to-coarse-grained transition between facies 4 and 12. Overall these facies associations represent fining-up sequences and indicate increasing stratification and sorting upward from massive basal gravels.

All three facies relationship diagrams indicate a basal facies association between the massive channel lag of facies 2 and planar

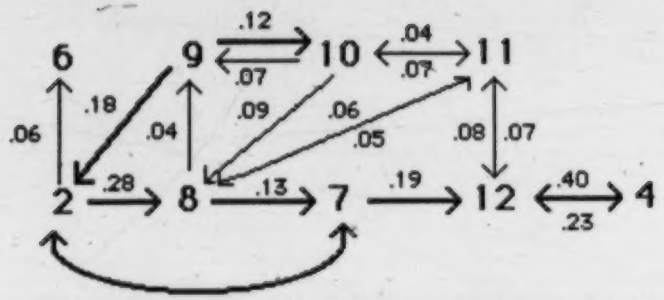

Figure 9. Lithofacies relationship diagram derived from data in Figure 8. Shows all positive "upwards" facies transitions in the study area. In all three facies relationship diagrams heavy lines represent transitions, which have positive values > 0.14, lighter lines < .014. The number above a horizontal line represents the right-to-left transition, the number below the left-to-right transition. For vertical arrows the upward transition is on the left, the downward transiton on the right.

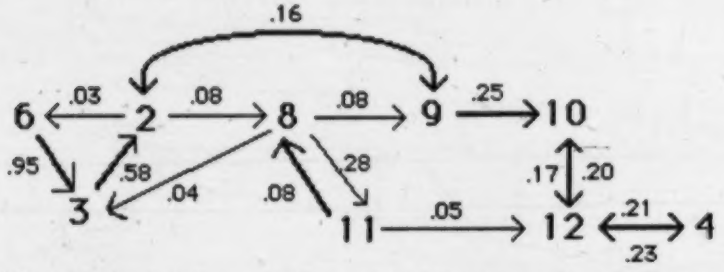

Figure 10. Lithofacies relationship diagram derived from data in Figure 8. Shows all positive "upwards" facies transitions. for Sections 2, 3, 5, and 8.

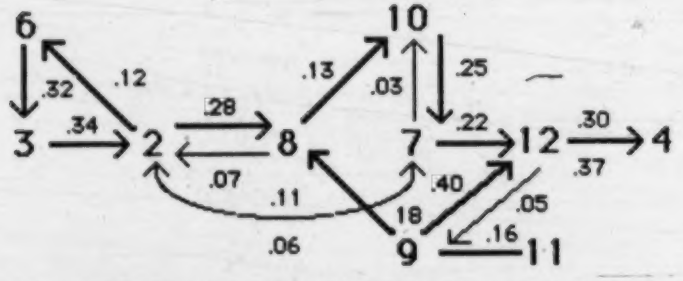

Figure 11. Lithofacies relationship diagram derived from data in Figure 9. Shows all positive "upwards" facies transitions for sections 6, 7, and 10.

cross-stratifed gravels of facies 6. This association suggests that bars with slip faces are a part of the basal facies association. Such cross-stratified gravels are largely excluded from proximal braided rivers in favor of massive to crudely horizontally stratified gravels (Rust, 1978). This facies association represents a relatively finer-grained medial reach of a braided river similar to the medial reaches of the Kicking Horse River described by Hein (1984).

The basal association between facies 2 and 8 is common to all facies relationship diagrams and characterizes an upwards transition from massive or crudely stratified to horizontally stratified gravel. This fining-up transition from massive channel-lag gravels to horizontally stratified and imbricate gravels is consistent with the formation of longitudinal bars or diffuse gravel sheets formed under progressively decreasing energy levels in braided rivers (Rust, 1978).

There is vertical succession from horizontally stratified gravels to trough cross-stratified sandy gravels in the pooled data. Similar upward transitions were attributed by Rust (1978) to the gradual infilling of an active channel complex in a braided river system by in-channel deposition of three dimensional gravelly bedforms. In Rust's model (1978) the continued aggradation in the channel and/or migration of a bar resulted in deposition of massive gravels. Therefore, coarsening upward transitions from finer-grained and cross-stratified facies 7 or 8 to facies 2 are interpreted to

represent continued aggradation of an active channel tract.

For all the data, fine-grained facies associations are more varied than the basal facies associations. The fine-grained association includes facies 7, 9, 10, 11 and 12, which were interpreted to reflect lower flow velocities associated with deposition on bar tops, nearly emergent diffuse gravel sheets or in the overbank areas. Rust (1978) suggested that the migration and gradual abandonment of an active channel would result in the accumulation of mud, although minor channels would still transport sands during flood events. Facies 9 sands were interpreted to represent these sands deposited during waning flow after major floods. The accumulation of mud in an overbank area is suggested by the other fine-grained facies of this association (facies 10, 11, and 12). In Chapter IV, facies 10 was suggested to reflect the presence of highly variable flow from peak floods deposits to stagnant water in ephemeral ponds. The close association between facies 9 and 10 indicates that after deposition of the bar-top sediments, there were periodic rapid increases in flow depths and velocities, possibly followed by long periods of emergence. Interbedded gravels, sands, silts and clays of facies 10 are truncated by progradation of diffuse gravel sheets (facies 2), or alternatively, the fine-grained facies association is completed by the upwards transition from facies 10 beds into silts and muds of facies 11 and 12.

A third major facies association was recognized between muds of facies 12 and gravelly facies 4. This association is comprised of stacked sequences of matrix-supported gravel and convoluted and contorted organic-rich mud. This association has not been documented as part of the vertical facies associations of a braided river. Based on the interpretations of the structures and textures in Chapter IV, it is suggested that these facies are representitive of side-entry debris flows of matrix-supported gravel, in which the major support mechanism was provided by cohesive strength of the viscous plug which moved downslope by laminar shearing in the basal zone of mud.

3) VERTICAL FACIES ASSOCIATIONS IN THE "VALLEY-FILL ALLUVIUM".

The facies relationship diagram for the thick sequences of alluvium measured in the Miller Creek valley and at the confluence of Glacier and Big Gold creeks, (referred to as "valley-fill alluvium") indicates an association between facies interpreted as channel lag gravels, bar forms with slip-faces and secondary channel fill (Figure 10). Similar to the pooled data the association between these facies is consistent with facies associations predicted for medial reaches of braided river system and records the formation of diagonal and transverse bars (and associated secondary channels) (Hein and Walker, 1974).

There is a preferred transition between stratified gravels of facies 8 and massive silts of facies 11, rather than the association suggested in the pooled data which places facies 11 in a fining-upward sequence intermediate between facies 10 and 12. This association is characteristic of most of the intermediate portions of the valley-fill sequence (23b) and is typified by thick massive silts with scoured upper surfaces interbedded with stratified gravels. A review of the recent literature indicates that such a facies association is not typical of braided alluvium common on sandur or braided outwash plains. However, similar depositional units of massive silts interstratified with massive gravel sheets are common features of arid Quaternary alluvial fans in Spain (Harvey,1984). Similar to this study, the silts in these arid alluvial fans, interpreted as extensive flood deposits, occur in the medial and distal sections.

The third facies association (cohesive debris flows) is not as prevalent in the latter stages of the valley-fill aggradational cycle as suggested by the pooled data. Finally, there is not a significant transition involving either facies 7 or facies 6. These facies require flow depths sufficient for the formation of slipfaces and their absence implies either shallow flow during aggradation of the valley-fill or, that high levels of sediment discharge ("hyperconcentrated flood flow") precluded their formation as suggested by N.D. Smith (1985) and Morison and Hein (in press).

In summary, the coarse-grained facies association in the valley-fill alluvium indicates the formation of a braided fluvial system prior to aggradation of the valley-fill. Fine-grained facies association indicates that the silts were flood deposits abruptly overlain by crudely stratified "hyperconcentrated flood flow" deposits and/or diffuse gravel sheets. Alternatively, diffuse gravel sheets became nearly emergent and were subject to fluvial conditions only during short-lived flow events.

4) FACIES ASSOCIATIONS IN THE SIXTYMILE RIVER TERRACE GRAVELS

The pooled data from Sections 6, 7, and 10 (the "Sixtymile River terrace gravels") (Figure 11) reveal both coarse and fine-grained associations that are similar to those of medial portions of the Donjek braided river system as described by Rust (1978). The basal, coarse-grained association is similar to that of the valley-fill alluvium (Figure 10). However, there is a stronger tendency than in the valley-fill alluvium for massive lags to be followed by horizontally stratified gravel. Major differences also occur in the number and complexity of associations between the fine-grained facies.

In the "Sixtymile River terrace" gravels there is a strong fining-upward association between facies 8 and 10, facies 8 and 7 or, a coarsening-upward transition between facies 10 and 7 (Figure 11). These trends suggest that facies 8 gravels were succeeded by finer-grained sediments deposited on bar-tops during waning floods, or deposition of small dune bedforms in shallow channels incised into the bar or gravel sheet surface. Other fine-grained facies associations are fining-upward transitions representing lowered flows on bar tops and in the overbank. (i.e. massive sands of facies 9 to silts of facies 11). As suggsted by Rust (1978) upward transitions from massive silts (facies 11) to muds (facies 12) record the final stages of abandonment of the fluival tract. The third facies association between facies 12 and 4 again indicates the presence of cohesive debris flows blanketing the fluvial gravels.

5) VERTICAL SEQUENCES IN THE SIXTYMILE RIVER ALLUVIAL PLAIN.

Markov chain analysis was not attempted on the upward facies transitions at Section 4 in gravels of the Sixtymile River alluvial plain due to lack of sufficient vertical exposure. However, the facies at Section 4 are sufficiently exposed (Figure B) to suggest two simple vertical columms (Figure 12) can sufficiently describe the major vertical facies associations.

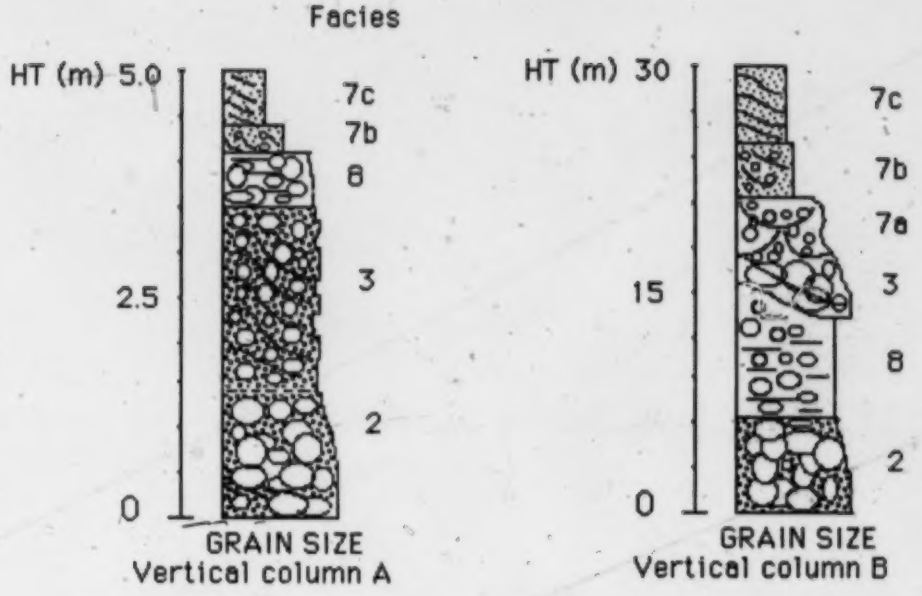

Figure 12 Vertical sequences from the "Sixtymile alluvial plain gravels. Vertical column A corresponds to a sequence through the point-bar. Vertical column B has been interpreted as a fining-up seqence through massive channel fill and trough cross-stratified pebble gravel.

In sequence A of Figure 12 the massive gravels show an upwards transition to lateral accretion cross-stratification (facies 5) and horizontally stratified gravel (facies 8). These two facies, in turn, are overlain by trough cross-stratified pebbly sands of facies 7. Sequence B indicates an upward transition from the basal massive gravel (facies 2) to horizontally stratified gravel (facies 8) and broadly trough cross-stratified gravel. These facies are capped by trough cross-stratified pebble gravel and trough cross-stratified sand.

Excepting the coarse grain size, the combination of facies associations in the first vertical sequence is characteristic of the sedimentary features recognized in active point-bar sequences (Allen, 1964; Puigdefabregas and van Vliet, 1978). These features include: (1) the scoured basal contact (with the underlying bedrock), (2) an upwards change from high energy cross-stratified gravels to lower energy cross-stratified sand, (3) an upwards diminution of the grain size, and (4) the presence of lateral accretion cross-stratification interpreted by Allen (1964) to reflect the lateral accretion of the point-bar (Puigdefabregas and van Vliet, 1978). In addition Gustavson (1978) describes very similar point bar sequences in the gravelly, meandering Nueces River of Texas.

C. LATERAL FACIES ASSOCIATIONS

Periglacial ice in the recently excavated gravels resulted in stable vertical exposures which allowed the measurement of the lateral facies associations in detail. In the organic-rich, fine-grained sections retrogressive thawing of ice of the organic-rich sediments overlying the gravel or fine-grained sediments of the terrace made lateral associations more difficult to measure. Most of the lateral facies associations as determined in outcrop are similar to those revealed by Markov chain analysis, but because the Markov chain is limited to a single narrow column, it reveals little about the scale of the lateral environments and ommited a rare, but important lateral transition between facies 4 and 9.

1) VALLEY-FILL ALLUVIUM

Lateral facies associations of "paleo-Miller Creek alluvial-fill" at Section 2 (Figure 13) are shown normal to the trend of Miller Creek. Lateral facies transition visible in this section are: (1) from massive to crudely stratified gravels (facies 2) to horizontally stratified gravel (facies 8), which reflects a lateral association between gravels interpreted as either channel lag or sediment-laden fluid flow and diffuse gravel sheets, (2) from massive sand (facies 9) to horizontally stratified gravel (facies 8); this lateral association indicates presence of bar-top sand/silt sheets adjacent

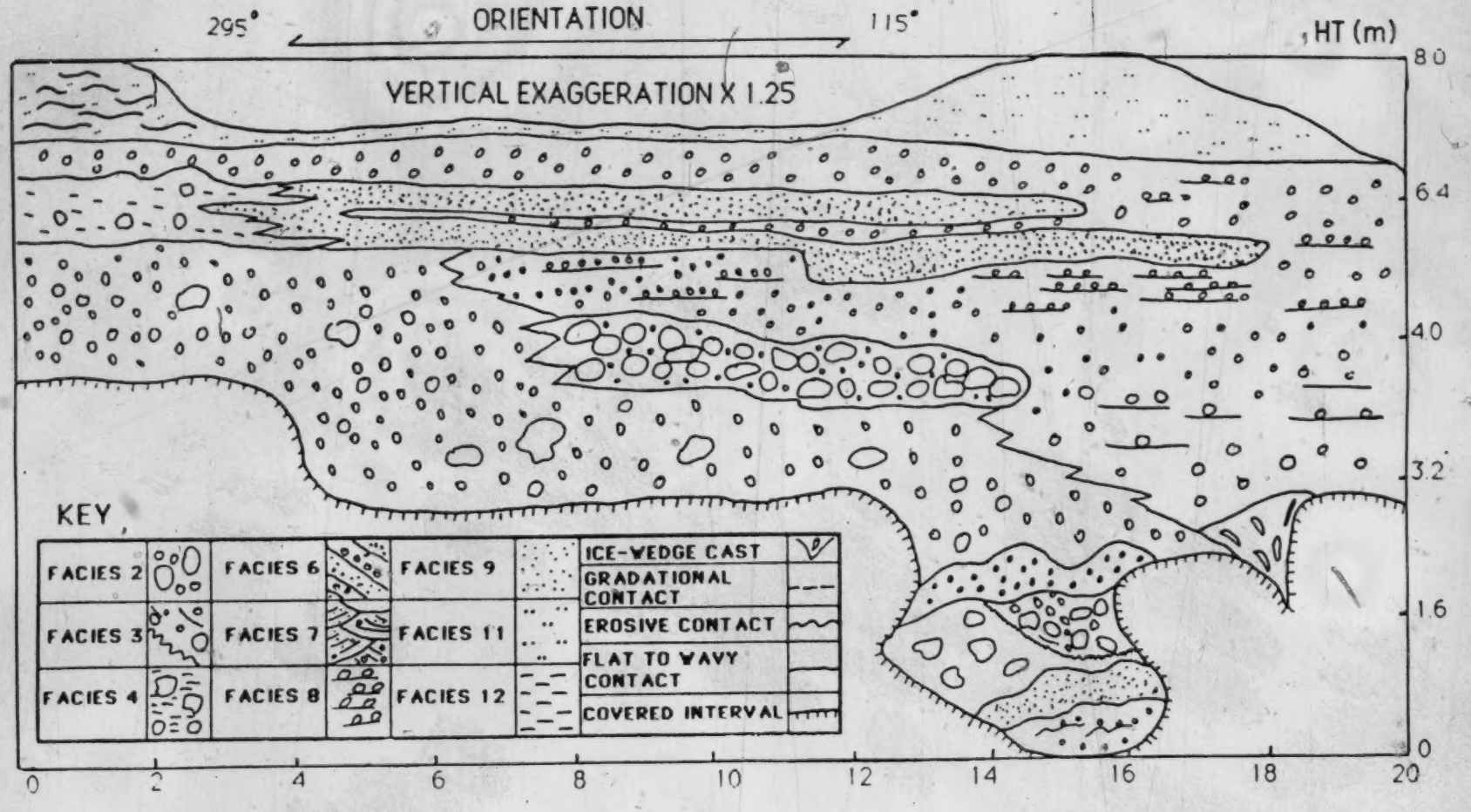

Figure 13. Lateral lithofacies associations at Section 2 in the Miller Creek valley interpreted as coarse-grained fan-apex gravels. Note the ice-wedge cast and lateral facies assoication between facies 4 and 9 interpreted as debris-flows infilling a small channel.

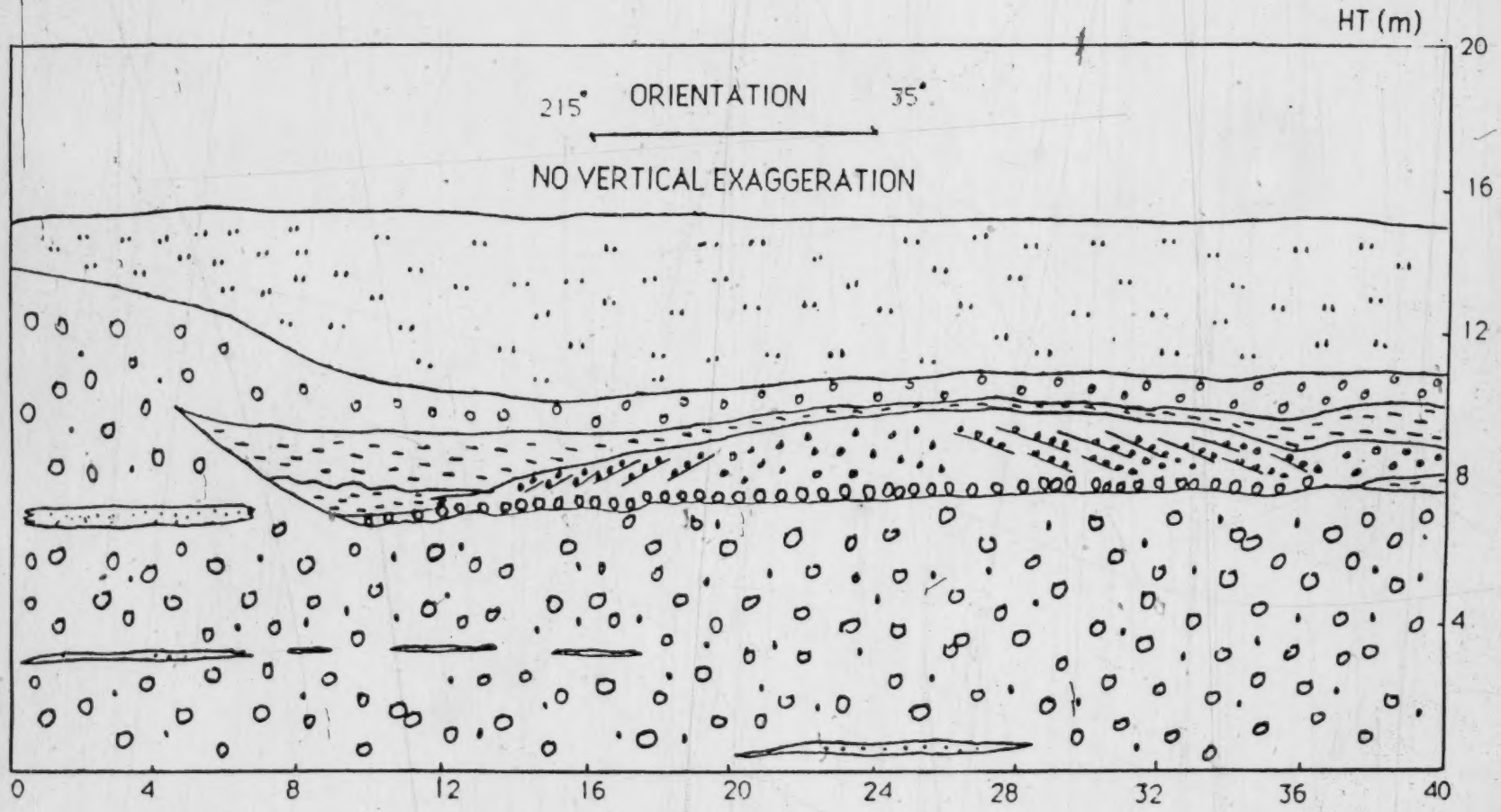

Figure 14. Lateral lithofacies associations at Section 3 in the Miller Creek valley interpreted as fine-grained channel fill. Symbols as in Figure13.

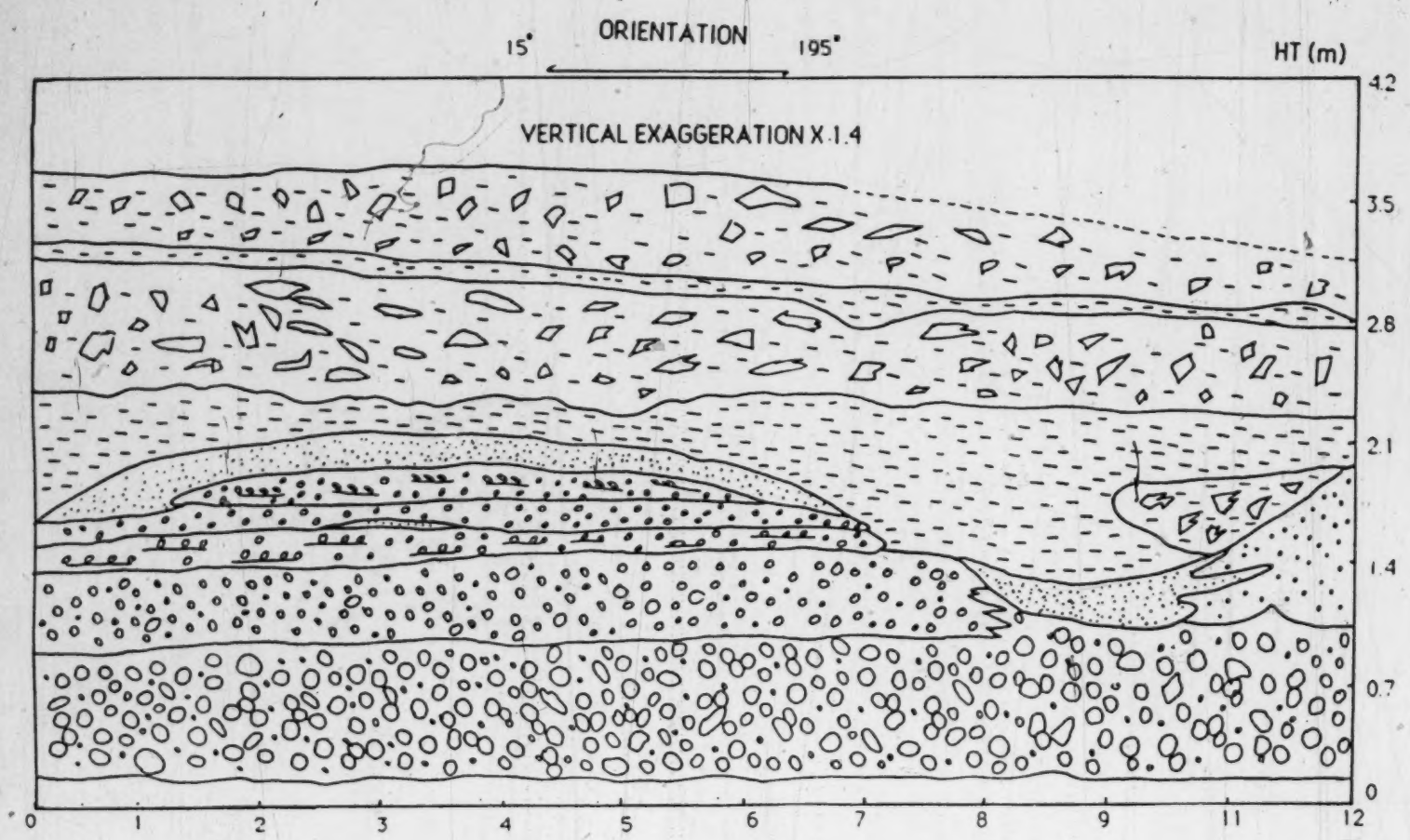

Figure 15. Lateral lithofacies associations at Section 7 in the Sixtymile River valley interpreted as fine-grained channel-fill and massive-stratified bar-core. Symbols as in Figure 13.

to diffuse gravel sheets, (3) a lateral association between massive sands (facies 9) and muddy-matrix supported gravels. These facies have been interpreted as bar-top sand/silts suspension deposits and cohesive viscous debris flows. This lateral association was not apparent from the Markov chain analysis (perhaps because of its rarity). It appears to indicate side-entry debris flows from valley walls were deposited on the valley-fill alluvial surface in pre-existing channels.

A lateral facies association between bar and channel sediments at Section 3 in the Miller Creek valley is shown in Figure 14. This association includes a lateral transition between massive facies 2 and crudely stratified facies 2, and a transition from planar tabular cross-stratified gravels of facies 6 to fine-grained facies 11 and 12 (including both muds and organics). There is an abrupt and steeply-dipping scoured contact between facies 11 and 12 and crudely stratified facies 2. This lateral association indicates a bar with an angle-of-repose slipface migrating laterally into a small channel scoured into massive gravels.

2) "SIXTYMILE RIVER TERRACE" GRAVELS

Lateral associations between facies 3, 2, 6, 8, in the "Sixtymile River Terrace" gravels at Sections 6 and 7 are similar to those of the basal association derived from the Markov chain analysis

and are interpreted as representing a deposition of gravels in the medial portions of a braided river. A clear lateral facies association is found at Section 7 in the Sixtymile River valley (Figure 15) between a concave-upward lens of coarse gravel and channel infill. There is an lateral facies transition from the horizontally stratified gravel interpreted as the core of a bar to mud and muddy-matrix supported debris flows which are infilling a laterally adjacent channel.

3) "SIXTYMILE RIVER ALLUVIAL PLAIN" GRAVELS

Lateral facies associations at Section 4 in the valley-center alluvial plain were measured over 80 m in a section parallel to the valley-axis of the Sixtymile River (Figure B). Lateral associations include those between facies 8, 5, 7, which are similar to those discussed for the Markov chain analysis of the vertical sequences. Other major facies transitions include: (1) transitions between facies 6 and 8 (i.e. from lateral accretion cross-stratification to horizontal stratification gravel), (2) transitions from broadly trough cross-stratified gravel to trough cross-stratified pebble gravel (facies 7a and 3), transitions from either planar tabular or horizontally stratified gravels (facies 6 or 8) to either broadly trough cross-stratified gravel or trough cross-stratified pebble gravel (facies 3 or 7).

4) "VALLEY-WALL ALLUVIUM"

Lateral facies associations between facies 1, 4, 12 and loess deposits of facies 11 are poorly documented due to lack of section continuity. In the most proximal exposures at Section 1 in the Miller Creek valley the beds are a monotonous sequence of facies 1 gravels which show no lateral or vertical facies transitions. As previously mentioned at Section 2 in the Miller Creek valley and Section 7 in the Sixtymile River valley there is a lateral association between sands of bar-top and debris-flows of valley-wall environments.

D. SUMMARY VERTICAL SEQUENCES AND ENVIRONMENTAL INTERPRETATIONS

Summary vertical sequences were derived from the facies relationship diagrams by placing in sequence the major facies associations in Figures 10 and 11. These summary sequences (Figure 16) indicate that the "paleo-Miller Creek valley-fill" and the "Sixtymile River terrace gravels" are similar to those sequences from alluvial fan and intermediate braided river deposits (Miall, 1977; Rust, 1978). Vertical sequences in "Sixtymile River alluvial plain" gravels are similar to those of the meandering river model, but differ in that they are coarser-grained than most other deposits of this setting. This is the first time where sediments found in thick "Colluvial Blankets" have been analyzed using facies, and as such there is no pre-existing facies

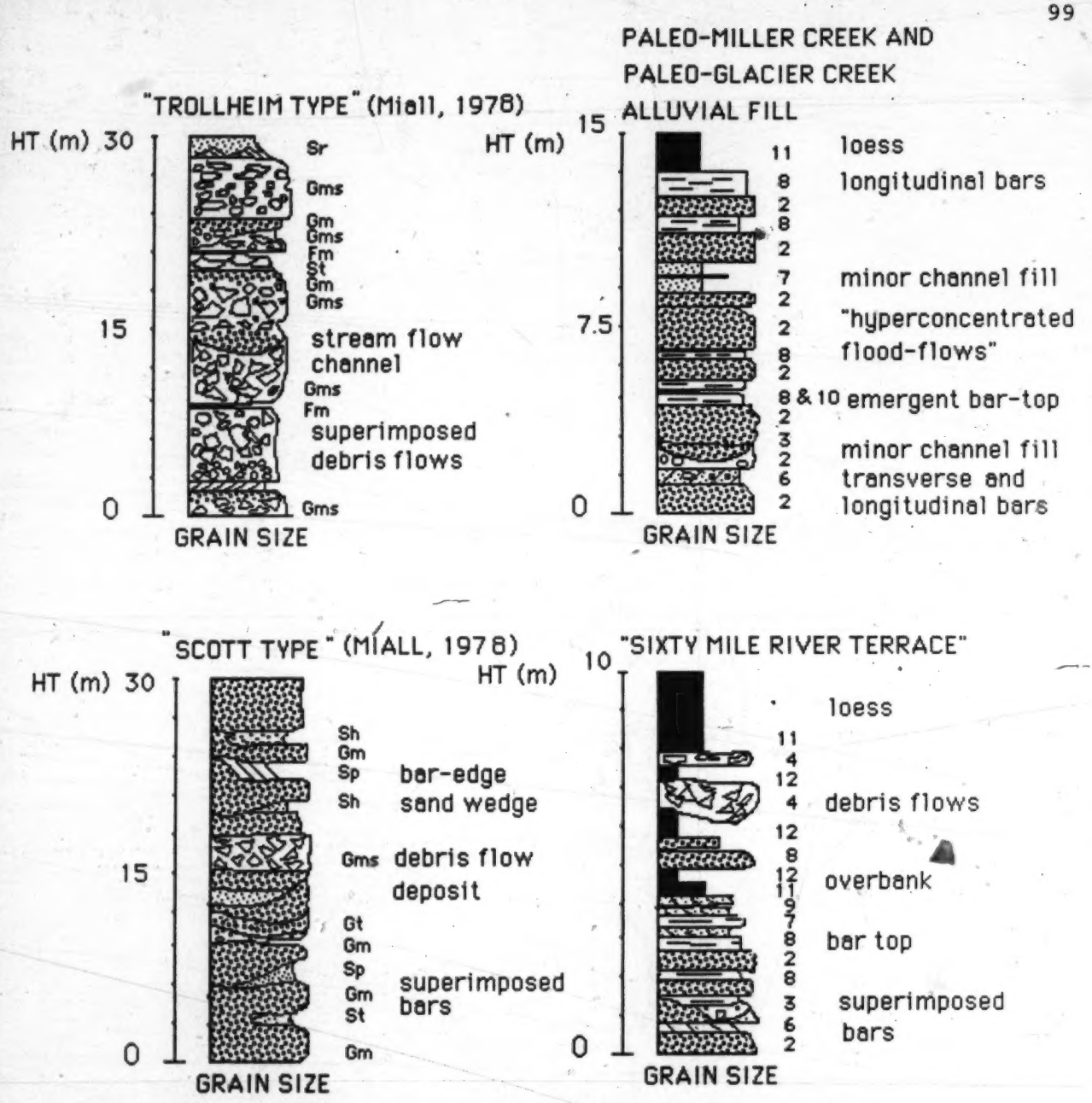

Figure 16. Vertical sequences of Miall (1978) compared to the summary sequences developed for the valley-fill alluvium of paleo-Miller Creek and paleo-Glacier Creek. Facies scheme follows that of Miall (1978) and this study. Note the similarity between the valley-fill alluvium and the "Scott-type" braided river and the unusual sequence in the upper half of the gravels

model. These sediments have been described elsewhere (Milner, 1976), nonetheless few studies have been based on a detailed analysis of their sedimentary structures and textures. The vertical sequences in the "Colluvial Blankets" (Figure 16) are sufficiently distinct from the braided and meandering river deposits, most notably in the abundance of cohesive debris-flow deposits (27 % at Section 6) and the interbedding of massive loess and wood accumulations.

1) VALLEY-FILL ALLUVIUM

The vertical facies sequence (Figure 16), the absence of channelling except near the base of the sections and the generally disorganized nature of the "paleo-Miller" Creek valley-fill alluvium suggests rapid emplacement of gravels with little opportunity for sediment reworking. The vertical and lateral facies association, (in particular the association between massive silts and massive gravels), and the proximal to distal trends from coarse, massive gravel to finer-grained stratified and cross-bedded gravel and sand suggests that the "paleo-Miller Creek" and "paleo-Glacier Creek" gravels are remnants of alluvial fan sequences. The proximal to distal facies transitions are similar to those trends in "fluvially dominated" alluvial fans described by Harvey (1984) . The vertical sequence developed by Miall (1978) for the Trollheim Fan is compared to the summary sequence of the valley fill alluvium in Figure 16. The absence of debris flows similar to Miall's *Gms* facies

in the Miller Creek summary sequence is distinctive. The paucity of debris flows in the study area may reflect the proximal location of Sections 2 and 5 within the fan (debris flows being most common in proximal settings) (McGowan and Groat, 1971). However, mud-matrix supported gravels were not observed in any of these gravels, so the absence of debris flows in the summary sequence more likely reflects the low rates of fine-grained mud produced from a metamorphic source area (Harvey, 1984).

2) "SIXTYMILE RIVER TERRACE" GRAVELS

Clasts in these gravels are generally better sorted, more rounded and of a more varied composition than the alluvial-fan gravels of "paleo-Miller Creek" and "paleo-Glacier Creek", suggesting a larger drainage area than for the alluvial fans. "Sixtymile River terrace gravels" have channelled bases, and are massive or horizontally stratifed, with less common planar tabular and trough cross-stratification.

The facies associations and summary vertical sequence (Figure 16) suggest fining-upward sequences from massive channel lags to horizontally stratified gravels consistent with the formation of diffuse gravel sheets with some minor scour-and-fill in smaller channels. Longitudinal and transverse bar development in a medial portion of gravelly braided streams is suggested by the development

of planar tabular cross-stratification (Rust, 1978). There is a strong similarity between the Miall's sequence for the "Scott type" river and the summary sequence derived for "paleo-Miller" Creek and "paleo-Glacier" Creek (Figure 16.) This indicates that the sequences in this study area were deposited in a dominantly fluvial environment.

3. "SIXTYMILE RIVER ALLUVIAL PLAIN"

Gustavson (1978) outlined sedimentary sequences in a gravel meander lobe system comprised of cross-bedded and horizontally bedded gravel. His sequence of sedimentary features through the lateral accretion deposits consisted of: (1) channel lag gravel, (2) large planar cross-stratification and horizontally bedded gravel and (3) interbedded horizontally bedded gravel and poorly-sorted sand and muds. His sedimentary sequence is virtually identical to vertical sequences for the Sixtymile River (Figure 12). The similarity of the vertical facies sequence to that predicted for coarse-grained point-bar development, along with the modern-day channels with abandoned lobes suggest that the Sixtymile River alluvial plain developed as aggrading gravelly point bar deposits in a meandering river.

4) "VALLEY-WALL SETTINGS"

The vertical summary sequence for this setting is shown in the upper portions of the vertical sequence of the "Sixtymile River terrace" gravels (Figure 16). The underlying rock type controls the nature of the sedimentary process on the valley walls. On steep valley slopes underlain by the metamorphic Nasina Series, the gravels are massive and angular proximal talus. Muddy matrix-supported debris flow deposits are found only on hillslopes where the underlying bedrock is andesite. The muddy matrix-supported debris flows on the intermediate to proximal fan surfaces were deposited as small lobes which followed pre-existing channels. Debris-flows into the Sixtymile River valley were larger and less confined by the pre-existing topography. Here, the debris flow facies appear localized and are commonly separated laterally by thick units of aeolian silt, ice and organics in which there is a paucity of gravel.

CHAPTER VII. PLACER DEPOSITS

A INTRODUCTION

The distribution of the observed sites of water-laid placers within the study area can be examined at three different scales: 1) the scale of individual bedforms (10^0 m), 2) an intermediate scale of the channel or channel reach (10^2 m), 3) a regional scale (10^4 m) (Table 5). The principles of fluid mechanics and sediment entrainment for grain-by-grain sorting are vital in understanding the formation of water-laid placers. These factors have been reviewed by Middleton and Southard (1984), Reid and Frostick (1985), and Slingerland and Smith (1986). The distribution of placer deposits at the intermediate scale (10^2 m) is the most economically important in the study area and closely fits the scale of modern-day mining operations.

Other studies on the sedimentology of water-laid placers on a channel-reach scale in ancient and modern settings include Minter (1975), Mosely and Schumm (1977), Minter (1978), Smith and Beukes (1983), Kingsley (1984) and Morison (1985a,1985b). These studies indicate the importance of specific topographic features such as bars, channels and river bends in creating zones of flow convergence (Slingerland and Smith, 1986).

On the regional scale, the formation of a water-laid placer is dependent upon external factors such as the regional geomorphology

TABLE 5 Observed sites of water-laid placers (after Smith and Minter,1980)

Sites	References
Large scale (10^4 m)	
Bands parallel to depositional strike.	Minter 1976, 1978, McGowen & Groat 1971
Heads of wet fans	Schumm 1977
Points of abrupt valley widening	Kuzvart & Bohmer 1978, Crampton 1937.
Points of exit of highland rivers onto a plain	Toh 1978
Regional unconformities	Minter 1976, 1978
Incised channelways	Minter 1978, Buck 1983
Intermediate scale (10^2 m)	
Concave sides of channel banks	Kuzvart & Bohmer 1978, Crampton 1937
Convex banks of channel bends	Kuzvart & Bohmer 1978
Heads of midchannel bars	Toh 1978, Smith and Minter 1980
Point bars with suction eddies	Toh 1978
Scour holes, especially at tributary confluences	Mosley & Schumm 1977
Inner bedrock channels and false bedrock	Adams et al., 1978
Bedrock riffles	Chenney & Patton 1976, Toh 1978
Constricted channels	Smith & Minter 1980, Smith & Beukes 1983, Morison 1985a
Small scale (10^0 m)	
Scoured bases of trough cross-strata sets	McGowen & Groat 1971, Smith & Minter 1980
Winnowed tops of gravel bars	Toh 1978, McGowen & Groat 1971

physiography, tectonic history and climate, (Adams et al., 1978), although ultimately the formation of a placer will depend upon the presence of a bedrock source. Few studies have considered the response of streams to changes in these external factors. Mosely and Schumm (1977) indicate the complexity of the response by fluvial systems to changes in external variables, and the importance of internally defined thresholds. Adams et al., (1978) describe the formation of a magnetite placer in a table-size scale-model of a drainage basin undergoing rejuvenation.

Placer studies which focus on the facies analysis of ancient sequences of gravel alluvium include those of the Witswatersrand (Minter, 1978), Clear Creek and White Channel placer gravels of the Yukon (Morison, 1983, 1985a, 1985b; Morison and Hein , in press). The depositional environments of the Witswatersrand placers correspond to a variety of braided river models (Minter, 1976). A broader "tectonic-environmental model" developed by Kingsley (1984) indicates the presence of transgressive sequences from braided and sinuous channels to a prodelta that are characteristic of a fan-delta environment.

The Clear Creek drainage basin resembles a braided system with facies found in upstream and downstream reaches of a gravelly, braided river (Morison, 1983, 1985a). Here, the sporadic gold distribution within an aggraded sequence of valley-bottom alluvium was attributed to the random dispersal of gold as point sources. In the White Channel Gravels of the Klondike gold occurred in proximal gravelly facies of a braided fluvial

environment (Morison, 1985b; Morison and Hein, in press). In proximal settings the placer formation was attributed to convergent flow in shallow channels during peak discharge intervals. In medial to distal positions heavy minerals were concentrated in channel sluice ways and on aggraded unit bars.

The model presented in this thesis describing the distribution of gold on a regional scale is based upon one possible sequence of events during the incision and aggradation of paleo- and modern Miller Creeks. It also shows the changing channel patterns of the Sixtymile River. This chronologic sequence is based on the available radiocarbon dates, the general physiography and geomorphology of the study area, and the clast provenance and paleo-flow directions (for discussion of the latter two topics see Appendix C and E).

B. MECHANICAL PRINCIPALS GOVERNING THE SORTING OF HEAVY MINERALS.

In most fluvial situations sand and larger particles are transported in contact with the bed as part of a traction carpet. This led Reid and Frostick (1984) to argue strongly against the use of the term 'hydraulic equivalence' (i.e. settling equivalence) in explaining the formation of water-laid placers. The bedload transport function is one of the best solutions to describe the bedload transport sorting of heavy minerals because it accounts for most of the forces acting during entrainment (entrainment sorting is based on

differential pickup of grains off the bed) and the tendency for smaller grains to hide among the larger grains (Slingerland and Smith, 1986). Finer and denser particles (especially gold) are more difficult to entrain because they have larger reactive angles through which they must roll (Slingerland, 1979). The threshold for entrainment of grains from a boulder gravel bed or on bedrock surfaces are poorly understood, but the most important grain behaviors during entrainment sorting are: 1) hiding of the smaller, heavier grains between larger clasts so that the smaller grains are sheltered from turbulence, 2) armouring, in which the finer grains are winnowed away leaving a coarse tail lag, and 3) trapping, in which grains in motion are captured in sites on the bed (Slingerland and Smith, 1986).

Bagnold (1954) defined shear sorting as the separation of grains into different horizons within a concentrated granular dispersion such as a moving bed layer or a grain flow. As discussed in Chapter II, inverse grading may result due to the dispersive pressures arising from grain collisions (Bagnold, 1954), or kinetic sieving (Middleton, 1970). Shear sorting and kinetic sieving are in part dependent upon grain density, and may be important in placer formation. There has been no discussion in the available literature on the importance of shear sorting or kinetic sieving in the formation of placers in cohesive, viscous debris flows similar to those found within the study area.

Considering the forces acting normal to the plane of shearing in a concentrated flow of cohesionless particles, it is expected that heavy

mineral grains would move upwards towards the free surface. If the shearing within the flow comes to an abrupt halt, a dispersion-equivalent sorting of the heavy and light grains would be preserved. In Chapter IV it was suggested that laminar shearing had occurred at the base of cohesive, viscous debris flows and was responsible for a vertical fractionation of the clasts based on size (inverse grading).

It would be expected that any heavy minerals within these flows would be sorted by the processes discussed above. However, any sorting experienced by a mixed population of light and heavy grains in a debris flow is overshadowed by the efficiency of debris flows as a transport mechanism. Entrainment of heavy grains into the laminar shearing zone of a debris flow would result in grain dispersion upwards into zones of increasingly higher flow velocities. As a consequence of entrainment, heavy mineral grains would no longer be in contact with roughness on the bed and the grains would be transported within the flow until dispersive pressures became too weak to support the the grains, or until the bed "freezes". Based on these considerations it is suggested that regardless of the efficiency of cohesive, viscous debris flows in sorting heavy and light grains, they appear to be an effective mechanism for transporting heavy grains once they have been entrained.

C. FACIES RELATED DISTRIBUTION OF GOLD IN THE STUDY AREA

In the only other study of detrital minerals within the study area, Glasmacher (1984) qualitatively noted the presence or absence of seventeen heavy minerals in concentrates and suggested that the variation in the distribution of the heavy minerals was barely significant. In this study, no attempt was made to describe the sedimentology of the samples collected.

In the present study 27 bulk samples were collected from five gravel and one sand facies. The highest concentrations of gold occurred in gravels of facies 2 (e.g. samples 2, 4, 21) or facies 3 (e.g. sample 18) (Table 6, Appendix D). In these two facies, the gold grain-size distribution falls into the lowest percentiles of the grain-size distribution (the largest grain of gold was ~ 5 mm on the a-axis). A close association between the gold, the coarse gravels of facies 2 and 3 and bedrock, suggest that most of the gold in the study area was transported either in contact with, or immediately above the bedrock. For typical clast sizes in these gravels (D = 16.3) it is fairly certain that during bedload transport of the gravel prevailing hydraulic forces would be well in excess of those necessary for the entrainment of gold. However, because the heavy gold grains are small, they were deposited quickly on the bed.

Bed roughness for flows which deposited sediments of facies 2 and 3 are controlled primarily by boulders which protrude into the flow. Roughness of bedrock substrates within the study area vary with rock type. Fractures in the metamorphosed schists of the Nasina Series between

Sections 1 and 2 in the Miller Creek valley form a trap or increase the roughness of the bedrock substrate. Andesite bedrock at Section 3 in the Miller Creek valley is "clay altered", does not have the extensive fracture pattern of the schists and would be a "smoother surface" with less roughness influencing the flow.

Facies 3 gravels were interpreted in Chapter IV as the product of channel cut-and-fill. The placer formation associated with this facies may be related to: (1) the scouring of the channel into pre-existing point sources within the gravels, and thus the formation of a residual lag or, (2) sorting processes related to differential entrainment and deposition of heavy mineral grains in zones of flow convengence similar to those described by Slingerland and Smith (1986). In the braided river environment major zones of flow convergence are found at the downstream tails of bars, in sluice-ways along the margins of "bank-hugging bars" and in small channels during peak flows (Slingerland and Smith, 1986). The concentration of placer gold in Sample 18 (Appendix D), which is a facies 3 gravel at Section 6 in the Sixtymile River valley appears related to convergent flow as small channels scoured into massive gravels. Hiding, armouring, and trapping of the heavy mineral grains may all have played a part in formation of placers in this facies.

Gold was not found in the facies 1 massive, poorly-sorted and angular gravels at Section 1 in the Miller Creek valley. However, this may have been due to sampling procedures, rather than a true measure of heavy mineral

abundances. Enrichment of heavy mineral grains was not found in bulk samples taken in the lateral accretion, cross-stratified, planar tabular cross-stratified, or horizontally stratified gravels (facies 5, 6, and 8). The absence of heavy minerals in these gravelly facies may imply the absence of upstream point sources.

In a model for the formation of placers in alluvial-fan settings, McGowan and Groat (1971) found that fine gold in the Van Horne Sandstone was concentrated at the base of trough cross-strata sets, which are most prevalent in the distal-fan setting. In this study area, trough cross-stratified pebbly sands (facies 7b) show enrichment of heavy minerals (e.g. sample 14, Appendix D). Placer formation in this facies is attributed to the greater reworking in the zone of scouring at the set bases. The gold would have been transported together with the sand as an "entrainment-size equivalent".

D. REGIONAL DISTRIBUTION OF PLACER GOLD

There are several examples of how the distribution of gold varies on the scale of the channel reach (Table 5). In this study it was possible to compare the distribution of gold at this scale between the "Sixtymile River terrace gravels" and Miller Creek alluvial-fan system.

Based on the historical records provided by Cockfield (1921) and the samples collected in this study, the richest concentrations of placer gold

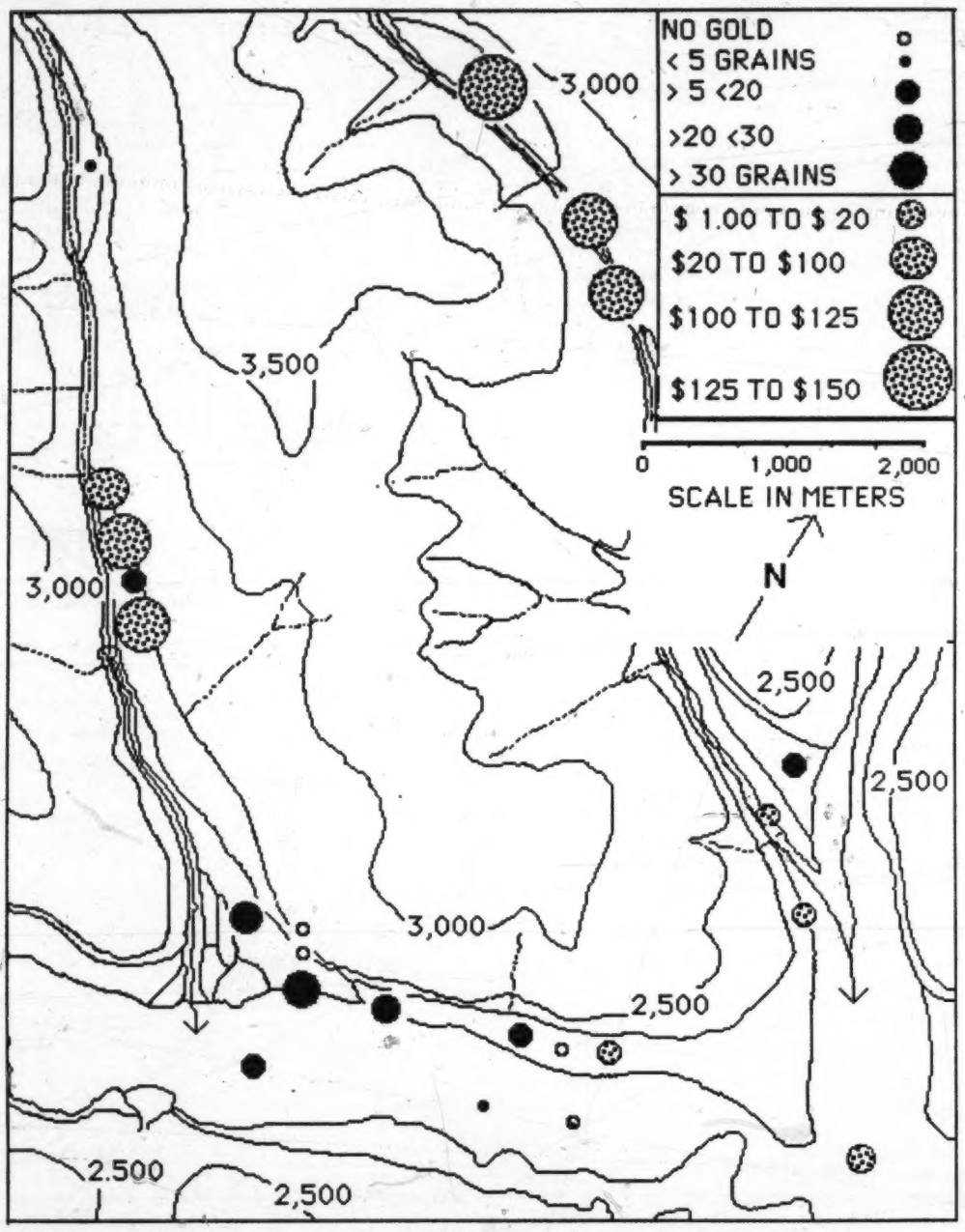

Figure 17. Distribution of placer gold in study area. Solid Circles samples collected by author, patterned circles are values reported by Cockfield (1921). A value of $100 reported by Cockfield for 12 square feet of bedrock at modern gold prices is greater than $ 1,000 per cubic yard.

were found on the benches above the modern creek (between Sections 1 and 2 in the Miller Creek valley and the base of Section 3 in the Miller Creek valley (Figure 17). A similar distribution of placer gold is suggested for Glacier Creek. It is fairly certain that most of the gold had its origin in vein systems within the Nasina Series (Glasmacher, 1984) at the headwaters of Miller Creek and was transported by fluvial proceses to the distal setting.

Historical records (Cockfield,1921) indicate the presence of a poorly defined "pay-streak" at the base of the gravels infilling the benches at Section 1 in the Miller Creek valley (Figure 2). This "pay-streak" is found in massive angular gravels which this study showed to have a preferred a-axis imbrication upstream. In Chapter IV these gravels were interpreted as the product of hyperconcentrated flood flows similar to those described by Smith (1986). In contrast, beds of facies 1, interpreted as proximal talus and colluvium at the same sites, are barren.

The aggraded sequence of alluvial valley-fill deposited in more distal settings (e.g. between Sections 2 and 3 in the Miller Creek valley), which is comprised of gravels deposited from heavily sediment-laden stream flow or, as massive sheets (facies 2 and 8) is also barren. However, over the same reach of the paleo-valley, there was a rich placer formed at contact between bedrock and the massive facies 2 gravels. Many authors (i.e. Chenney and Patton, 1967; Morison, 1985b; among others) have tried to explain the high concentration of gold near bedrock in such settings. As suggested earlier, cohesive, viscous debris flows and possibly

"hyperconcentated flood flows" which are abundant in this setting, are efficient mechanisms for the transport of heavy minerals.

Studies on alluvial fans (i.e. Bull, 1977) and more recently in the lahars of Mount St. Helens (Smith, 1986) suggest that as debris flows move down-valley, flow becomes increasingly turbulent. As fluid turbulence increases, heavy mineral grains are more likely to be trapped on the bed. The presence of numerous void spaces in alluvial-fan gravels between Sections 2 and 3 would form a highly efficient sieve capable of trapping gold grains. The opportunities for hiding, armouring and trapping are high, so it is unlikely that any significant fraction of the heavy mineral grains could be carried as bedload once flow became fully turbulent. In addition, the formation of secondary placer concentrations in zones of convergent flow would be limited further by the paucity of zones of flow convergence in shallow flows on alluvial fan surfaces. Therefore, a preferred site of placer formation occurred where gold was trapped by lag gravels on or near bedrock near the apex of the valley-fill alluvium.

Heavy mineral placers in the "Sixtymile River terrace gravels," interpreted as products of a medial braided river, are found in facies 2 and 3. Similar to the model proposed by Morison (1985a) for the distribution of placers at Clear Creek, the flow associated with formation of residual lags and the sporadic distribution of upstream point sources led to the formation of dispersed pockets of detrital gold enriched in zones of increased flow convergence. These zones of flow convergence would be controlled by the

spatial relationships of the channels and bars with preferred concentrations expected along leading edges of the bar-head and zones of flow convergence around bars or in channel sluice-ways (Smith and Buekes, 1983; Slingerland and Smith, 1986).

In the gravels of the "Sixtymile River alluvial plain" none of the bulk samples contained an appreciable enrichment of placer gold, although there was an abundance of other heavy minerals in gravels of facies 2. Gold within this setting is coarse and widely dispersed (M. Connors, personal communication 1984). Here, the economics of the mining operations is controlled more by the ease of stripping the thin overburden and the processing of large volumes of "low-pay" gravels rather than the placer enrichment of the gravels by fluvial sorting processes. Possible explanations for the lower concentrations of gold in this environment are: (1) a dilution of the grade by mixing with gravels of the Sixtymile River or, (2) flushing of the gold from the system during the incision of the Sixtymile River to its present level. This would occur in manner similar to the "flushing" of the heavy minerals noted by Adams et al, (1978) in their stream table model.

E. CHRONOLOGICAL HISTORY OF INCISION AND VALLEY-FILL AGGRADATION AT MILLER CREEK.

The interpreted environments of the surficial sediments reflect changing alluvial systems and changing hydrological processes governing the transort, deposition, burial and subsequent preservation of the placer deposits . A careful analysis of the environments can provide insight into the processes governing the distribution of placers and the location of favorable sites for future exploration.

Within the tributary drainages, the favorable sites of placer accumulation include the base of the incised tributary and the zone of flow convergence formed at the confluence of the broad Sixtymile "braided river", and "paleo-Miller Creek". After reaching a local base level, "paleo-Miller Creek" underwent a period of valley-widening directed down the Sixtymile River trunk valley (Figure 19a). This widening resulted in the accumulation of placer deposits over a broad "paleo-Miller Creek" valley bottom. Within the Sixtymile "braided river", placers were sporadically distributed in zones of flow convergence that developed around bars, in channel sluice-ways and at heads of bars. Placer formation was not necessarily restricted to the central portions of the alluvial tract and favorable sites for placer formation may have occurred in gravels adjacent to the valley wall. Lateral widening of the valley was accompanied by an upvalley migration of the apex of the valley-bottom alluvium. At this point of abrupt valley-widening

there was a fundamental change in fluid flow and bed roughness that made it the most favorable site for placer deposits.

Figure 19b indicates how the vertically aggrading sequence of the alluvial fan sediments may have looked when prograding into the "Sixtymile braided river" valley. Radiocarbon dates from *in situ* peat interbedded with the fan gravels (GSC-3934) and *in situ* wood from above the uppermost gravel (GSC-4032) indicate this stage of fan aggradation was completed > 40,000 B. P. (see Appendix A). Erosion of the distal portions of the fan by the Sixtymile River resulted in reworking of any placers formed in the distal portions of the fan. This may explain placer enrichment on bedrock in this location (M. Brisbois, personal communication, 1984) and the enrichment in trough cross-stratified sands (facies 7a) of the "Sixtymile braided river".

At approximately 26,000 B P (Figure 19c) debris flows deposited sediment on the "Sixtymile River terrace gravels" and Miller Creek was directed to the south-west side of the paleo-valley. Timing for the subsequent incision and formation of the modern channel of Miller Creek is difficult to judge, but may have occurred concurrently with this change in the channel pattern of the Sixtymile River. The gravels at Section 1 preserved during the incision of modern Miller Creek are not a favorable site for placer accumulation. Rich accumulations of placer gold in this setting point to the presence of local bedrock point sources.

During the last glacial period the thick loess (Figure 19d) was deposited on both the "Sixtymile River terrace gravels" and the "paleo-Miller Creek valley-fill". During the Holocene minor modifications of the landforms included vertical aggradation and valley widening of the modern Miller Creek channel.

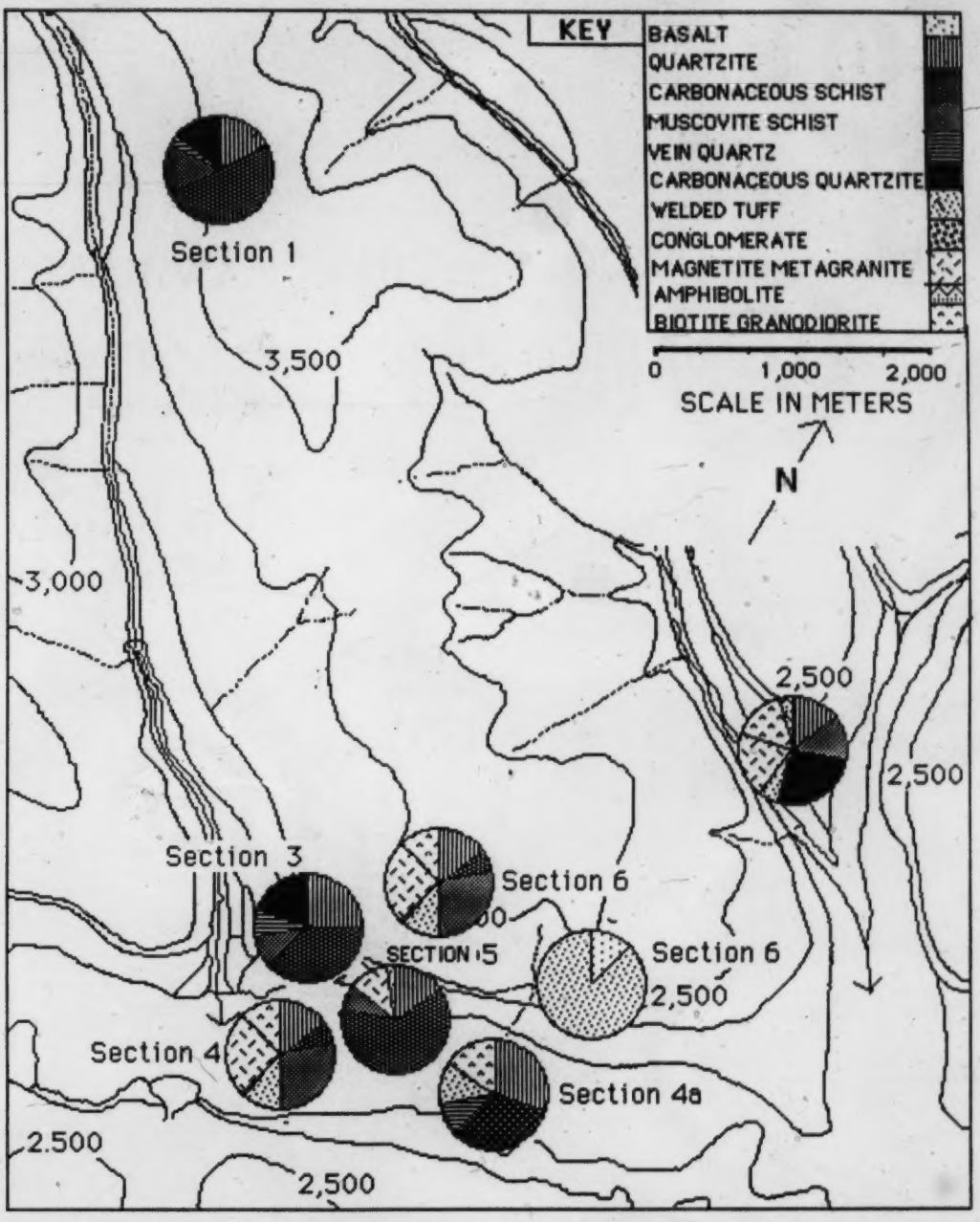

Figure 18. Map showing lithological composition of clast in the Sixtymile River area

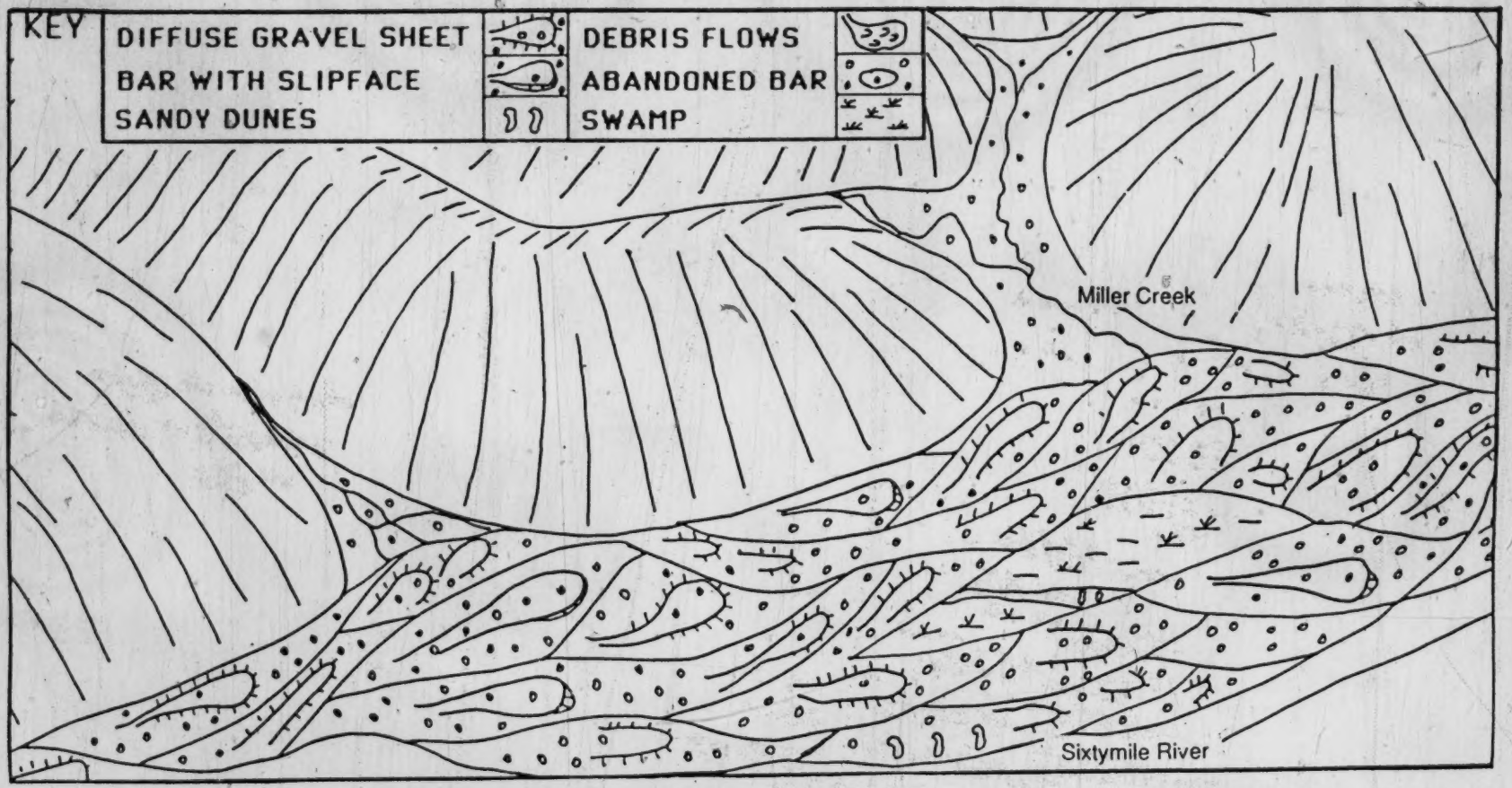

Figure 19a. Plan sketch depicting sedimentary environments of the Sixtymile River and Miller Creek prior to valley-fill aggradation of "paleo-Miller Creek". This may correspond to the Happy time-stratigraphic interval of Hopkins (1982).

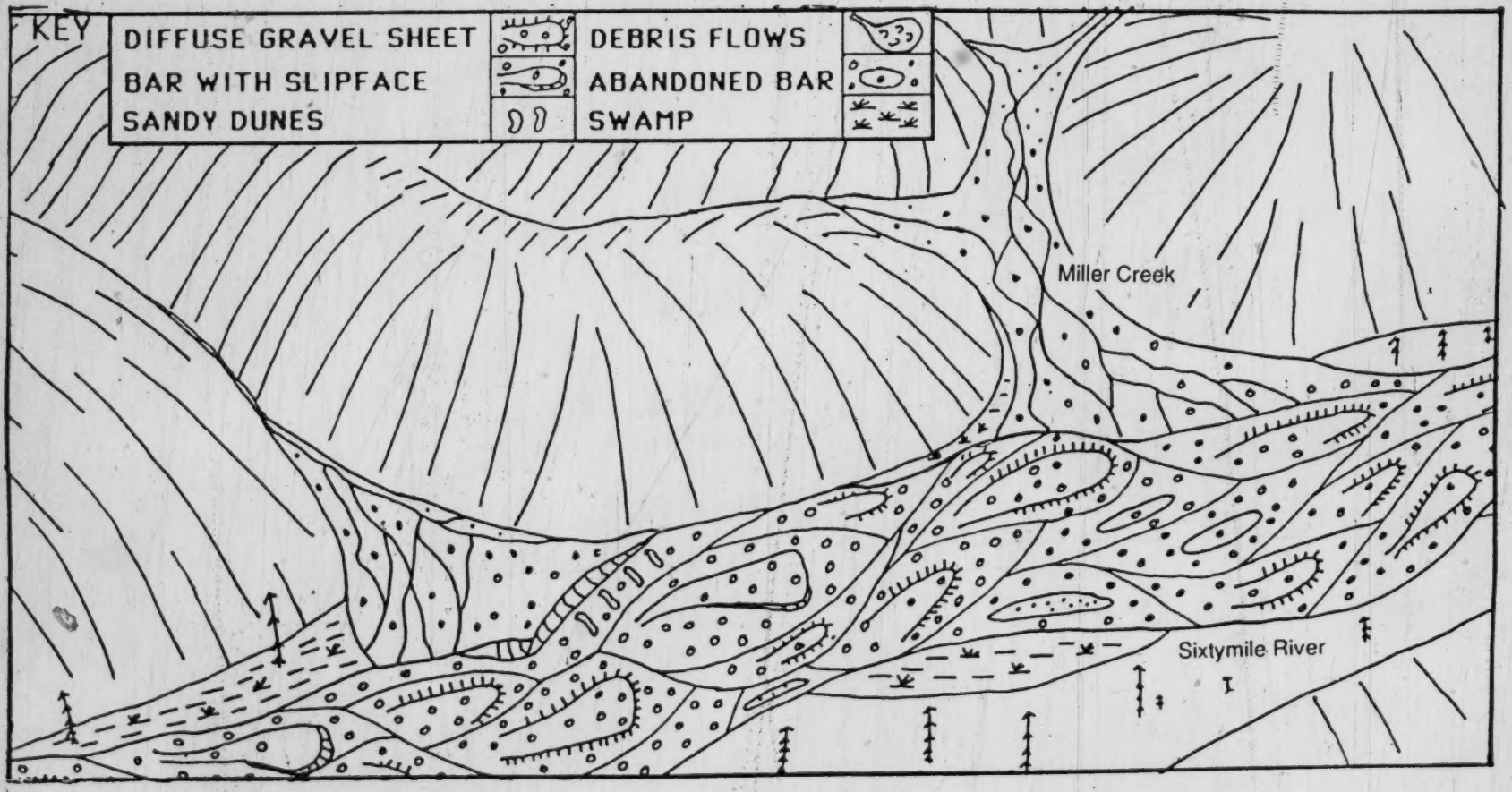

Figure 19b. Plan sketch depicting the aggradation of an alluvial fan and back-filling of Miller Creek valley, which was completed >40,000 yr. B.P. Note the erosion of the distal-fan sediments by the Sixtymile River.

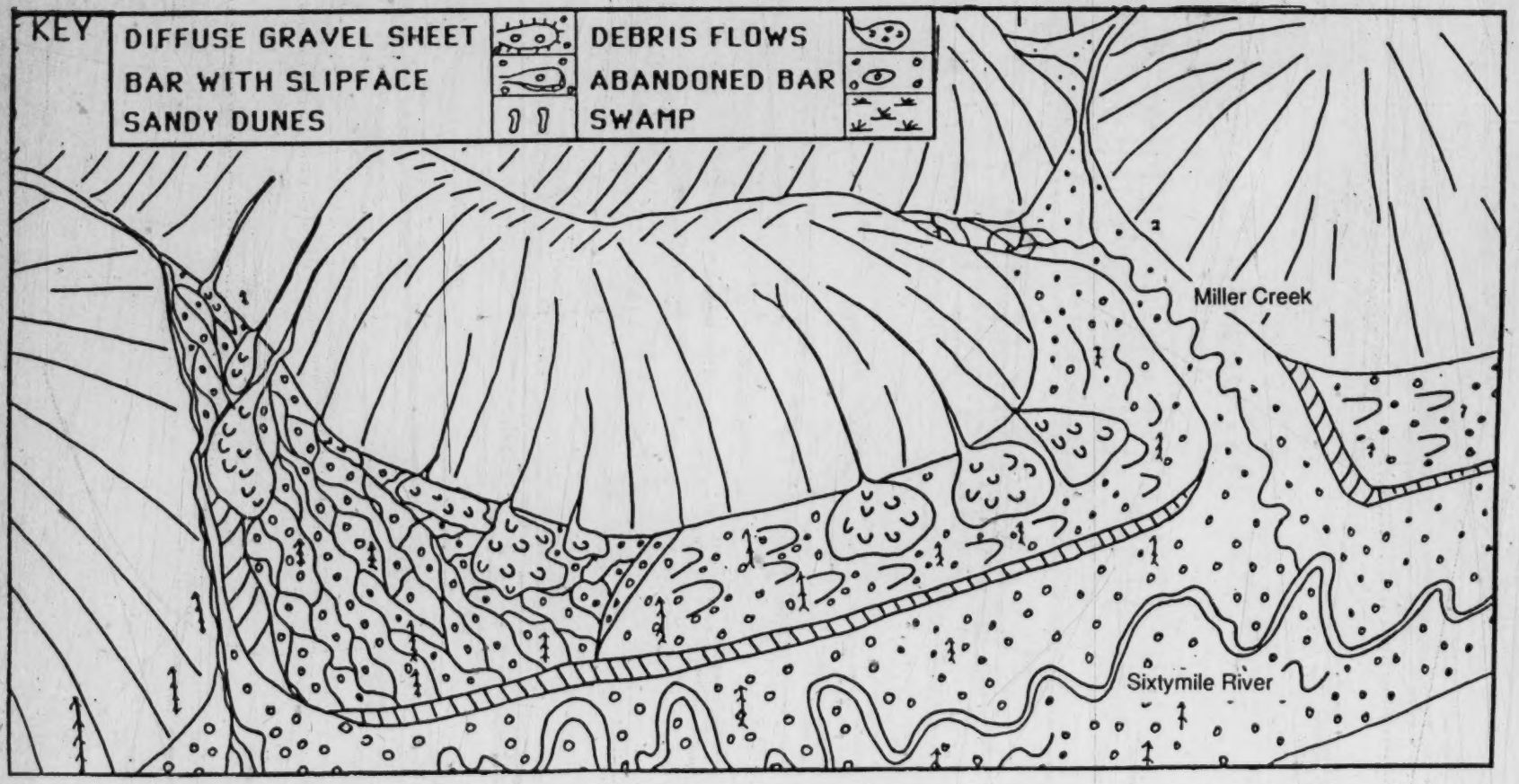

Figure 19c. Plan sketch depicting the onset of debris-flow sedimentation at approximately 26,000 yr. B.P. which covered the terrace and forced Miller Creek to the south-west side of the valley. During incision, Sixtymile River has incised into the broad alluvial plain and under gone a change in channel pattern from braided to meandering. Miller Creek is beginning to incise a new channel.

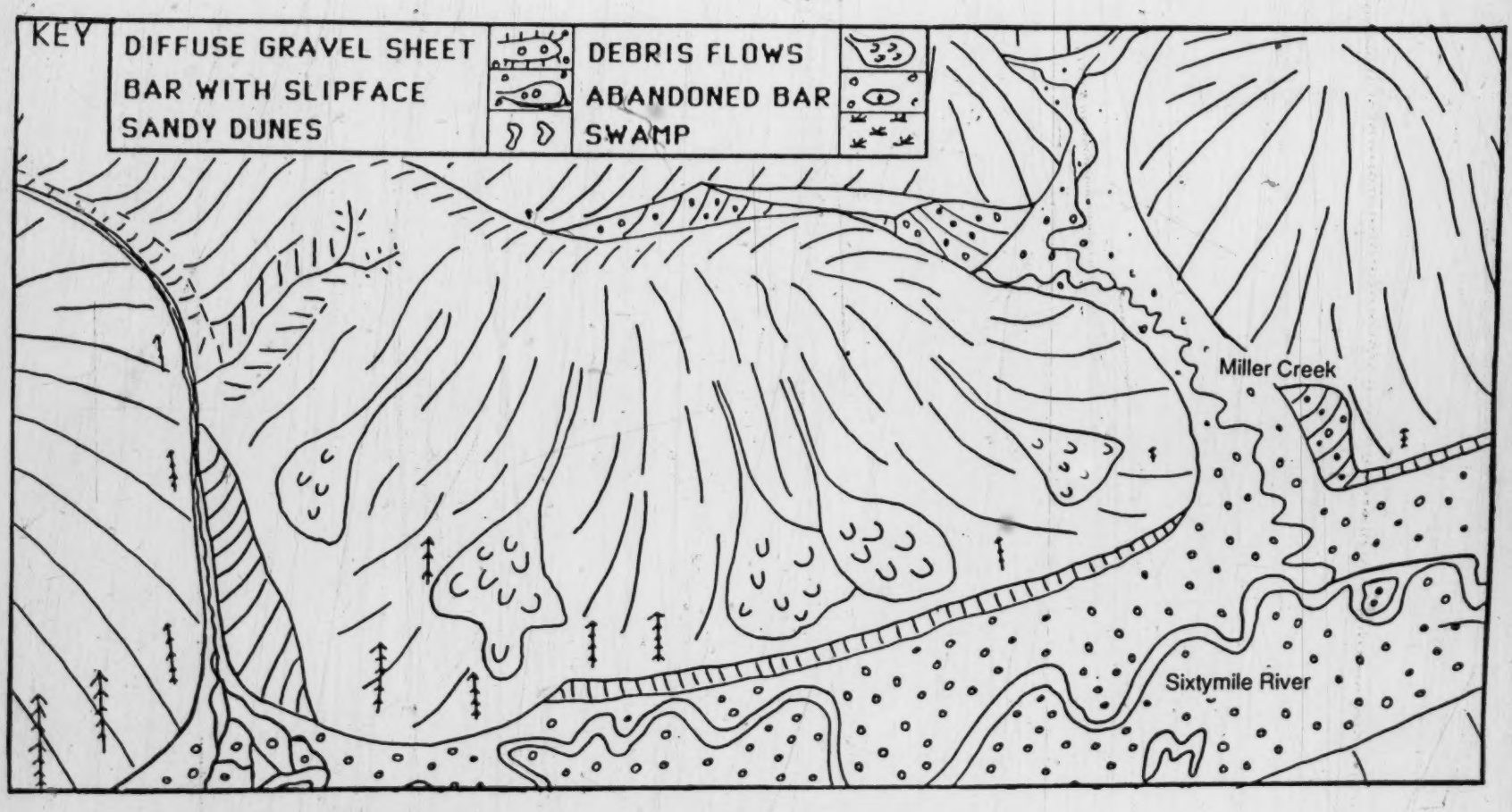

Figure 19d. Plan sketch depicting the Sixtymile River area as it appeared at the turn of the century. Continued debris-flow and loess sedimentation have resulted in a subdued topography. Miller Creek has completed incision of the modern channel and is widening the valley laterally. Note the remnant of the alluvial valley-fill at Glacier Creek.

F. FUTURE PROSPECTING

The distribution of gold-bearing gravelly sediments in the Sixtymile River area is dependent upon both the sedimentology of the gravels and the geomorphic history of the area. Success in future prospecting will depend upon understanding how the distribution of the detrital gold is related to the depositional environments of the gravelly sediments and to the evolution of the landforms. It is hoped that a synthesis of the results from this study will enhance future results from exploration and testing programs such as drilling and trenching.

Within the Sixtymile River area four different types of economic gold-placer deposits occur: 1) poorly-sorted, angular gravels in which concentration of placer gold occurred during downcutting of pre-fan braided stream and fan-head (gulch) topographies; 2) gold-bearing braided stream gravels which were deposited in the "paleo-Miller Creek" valley during a period of valley widening before fan aggradation, reflecting redistribution of the orginal gulch paystreak gold concentrations near the paleo-valley thalweg; 3) laterally discontinuous pockets of detrital mineral concentrations in braided stream deposits occurring at the base of the medial and distal alluvial fan sequences and on the terrace of the Sixtymile River; and 4) topographically lower, but still economic concentrations of placer gold occur in gravels in the alluvial plain of the Sixtymile River valley.

In general, where there has been preservation of either active or inactive fluviatile gravels, the strata immediately above the bedrock surface has produced placer gold. The value of placer gold on these bedrock surfaces, and the spatial distribution of the gold is dependent upon the proximity to bedrock point sources, the hydrodynamic conditions during the deposition of the gravelly sediments and the evolution of the associated landforms. Successful future prospecting in the area depends upon the recognition of the unmined bedrock surfaces preserved under the gravelly sediments.

During the course of this study, two different areas of active alluvium and five different areas of inactive alluvium were recognized that may warrant future exploration.

1. ACTIVE ALLUVIUM:

1) the undredged part of the active alluvium of Big Gold Creek between the confluence of Big Gold and Little Gold Creeks and downstream to the mouth of Glacier Creek;

2) the Sixtymile River alluvial plain upstream from Miller Creek to the mouth of Bedrock Creek.

2. INACTIVE ALLUVIUM

1) the wedge-shaped fraction of bedrock terrace which is buried

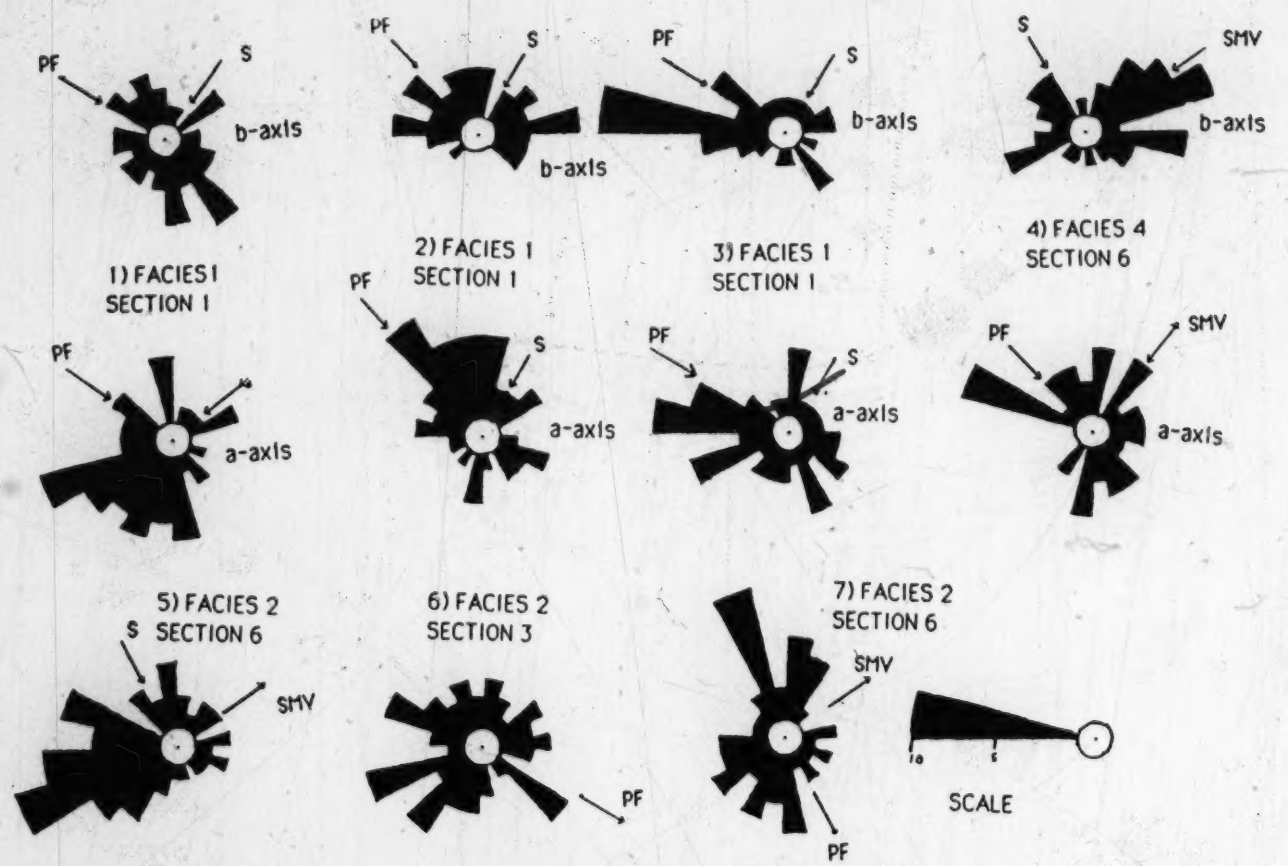

Figure 20a. Rose diagrams for the dip direction of the a-b planes measured for elongate pebbles. For rose diagrams 1-4, a-axis imbricate and b-axis imbricate clasts have been plotted. For rose diagrams 5-15 only b-axis imbricate clasts were used. For most samples the orientation of the a-b plane of b-axis imbricate clasts reflects the upstream paleoflow direction. For other symbols refer to Figure 20b.

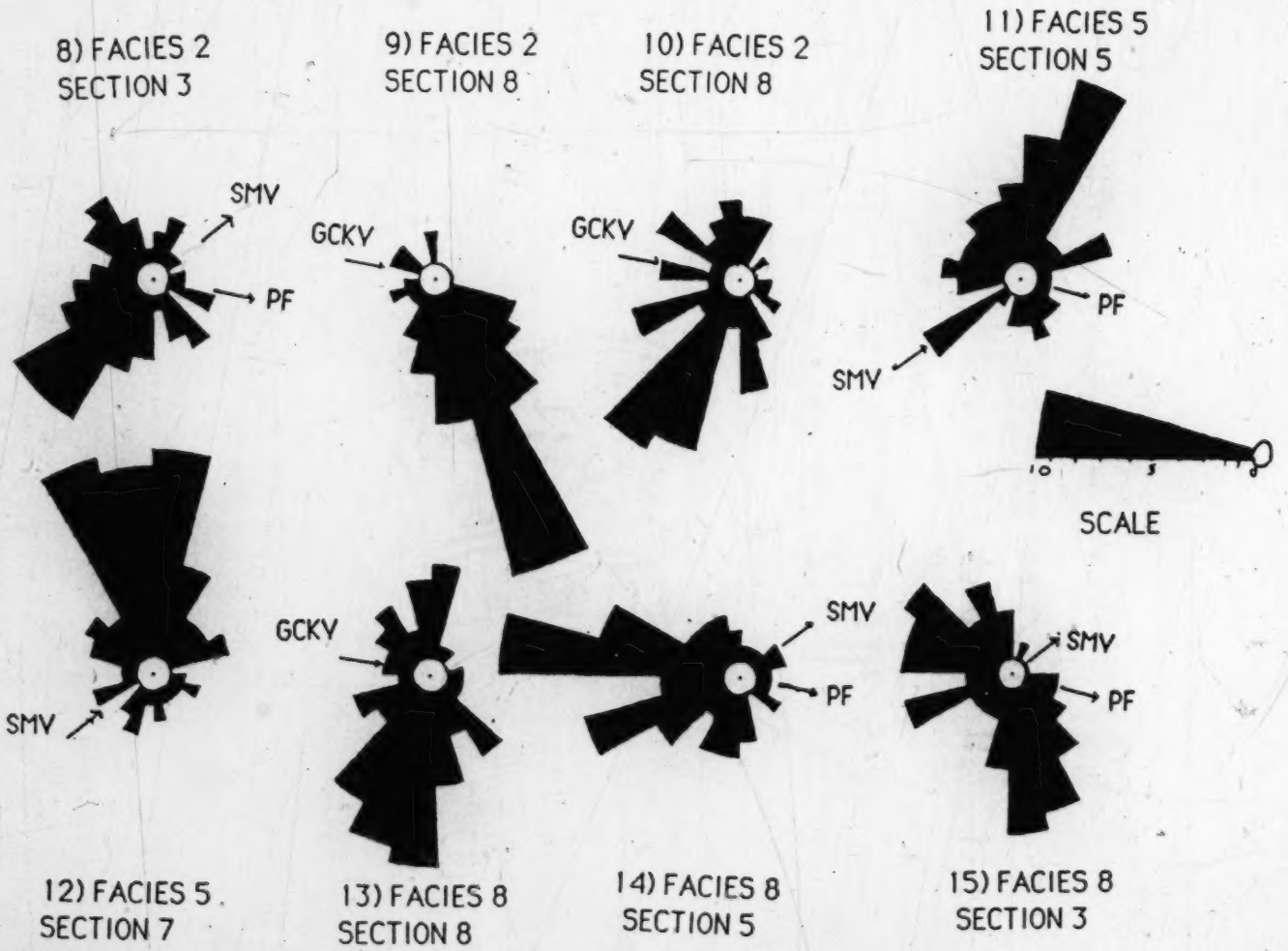

Figure 20b. Rose diagrams for the dip directions of the a-b planes measured for elongate pebbles. S=trend of local valley-wall slope. PV= trend of the paleo-valley. SMV= orientation of the Sixtymile River valley. GCKV= orientation of the Glacier Creek valley.

beneath the alluvial-fan/valley-fill gravels at the mouth of Glacier Creek;

2) similar wedge-shaped fractions of bedrock underlying the alluvial-fan gravels at the confluence of Miller and Bedrock Creeks with the Sixtymile River. At Miller Creek the largest unmined portion is buried along the northeast side of the valley under approximately 20 m of gravel from below Section 2 (Figure 2) to Sections 3 and 5 (excluding portion mined underground);

3) the gravels of the Sixtymile River terrace downstream from the confluence of Big Gold Creek and the Sixtymile River (an area of approximately 5.0 by 0.5 km);

4) gravels of the Sixtymile River terrace upstream of Miller Creek to the mouth of Bedrock Creek;

5) gravels of the Sixtymile River terrace on the north side of the Sixtymile River valley presently being mined between Big Gold Creek and Miller Creek. As discussed in the text and shown in Figure 19b, the distribution of gold in this setting (and elsewhere on this same terrace) should be based on the spatial relationships at a channel scale and the gold values do not necessarily decrease towards the valley margin.

CHAPTER VIII CONCLUSIONS

Surficial deposits in the study area were deposited in four different depositional environments. The vertically aggraded sequence of gravels at Sections 1, 2, 3 and 5 correspond most closely with that of the "Scott-type" braided river (Miall, 1978) or fluvially dominated alluvial fans (e.g. Harvey, 1984). Vertical and lateral facies associations at the base of Sections 3, 5, 6, and 7 in the Sixtymile River valley are similar to those in downstream reaches of the Kicking Horse River (Hein and Walker, 1977) or distal reaches of the Donjek (Rust, 1972, 1978). Gravels of the "Sixtymile River alluvial plain" at Section 4 have been interpreted as deposits of a coarse-grained meandering river dominated by lateral point-bar accretion. In the fourth environment, alluvium found on valley-walls near Section 1 and the upper portions of Sections 3, 5, 6 and 7 is dominated by cohesive, viscous debris flows and aeolian loess.

In the Miller Creek valley, there is a proximal to distal transition from alluvial fill to alluvial fan deposits. The major proximal to distal facies transitions are from massive, angular and poorly-sorted gravels interpreted as the product of "hyperconcentrated flood flows" or "sediment-laden flows" to moderately-well sorted, subrounded and stratified gravels deposited in shallow unconfined flows. Major facies sequences occurring within these gravels are upwards transitions from massive to crudely to horizontally

stratified gravels with interstratified massive silts. Sedimentary structures in the gravels of the alluvial fan (such as the inverse grading in clays and gravels of facies 10 and the dominance of crudely stratified gravel sheets (facies 2) suggest that flow events on the fan surface occurred as sporadic high-discharge events in shallow, unconfined channels.

The vertical sequence of facies at Section 3 in the Miller Creek valley and Section 5 in the Sixtymile River valley record the formation of an alluvial braidplain on the "Sixtymile River terrace" before the aggradation of the valley-fill of "paleo-Miller Creek". The lateral and vertical facies associations suggest a strong similarity to the medial reaches of a gravelly braided river. Burial of these gravels by debris flows resulted in preservation of a fining-up cycle recording channel-fill and migration of longitudinal and transverse bars of an active channel complex. This portion of the alluvial tract became inactive and started to accumulate sand succeeded by mud only during peak floods.

Two different vertical facies sequences were recognized in the deposits of the meandering Sixtymile River: (1) channel-lag gravel (facies 2) overlain by lateral accretion cross-stratification (facies 5) which are capped by cross-stratified sands (facies 7); and 2) channel-lag gravel plus scour-and-fill (facies 3) capped by cross-stratified pebble gravels and sands of facies 7a-c. Sequence 1 is identical to that of gravelly point-bars of the Nueces River as predicted by Gustavson (1978). Sequence 2 is interpreted as a fining-upward sequence produced by channel infill by

massive gravels, succeeded by sedimentation from migrating gravelly dunes.

The valley-wall alluvium is comprised of interbedded sequences of muddy matrix-supported gravels (facies 4) and muds (facies 12) which are interpreted as stacked, cohesive viscous debris flows. These debris flows may be interstratified with facies 11 silts, interpreted as aeolian loess. Bone fragments representing a diverse faunal assemblage of Late Pleistocene mammals were entrained as detritus from the surface of the surrounding slopes and incorporated into the debris flows.

Significant accumulations of water-laid placer gold are found in portions of the alluvial fan, braided river and meandering river gravels but not in debris-flow gravels of the valley-walls. Placer gold is found in channel-fill of the proximal "paleo-Miller Creek gravels" (facies 1), and channel-lag gravels (facies 2) or channel scour-and-fill gravels (facies 3) at the base of "paleo-Miller Creek" and in the "Sixtymile River terrace gravels". Theoretical considerations suggest that sorting of light and heavy mineral grains may occur in the laminar shearing zone of a debris flow. However, in the study area, debris flows are more important as efficient processes for the transportation of heavy minerals and not the concentration of gold.

Few studies are available that quantitatively describe the hydraulic forces that would result in sorting and thus placer formation in similar grain-size distributions of heavy and light minerals found in facies 2 and 3. The grain-size distribution of the heavy minerals (which occur in the lowest

percentiles of the gravel grain-size distribution) suggests that the heavy mineral grains were hidden in the interstices of the larger gravel clasts and formed a residual lag. These grains would be entrained as part of a traction carpet only during peak flows, or during scouring of the bedrock. The trapping of heavy mineral grains in the void spaces of the poorly-sorted gravels may explain the decreased gold content in the aggraded sequence of "paleo-Miller Creek gravels" In sandy facies (facies 7a-b), in which there was a concentration of heavy minerals, the scouring at the trough bases appears to be the primary process controlling placer formation.

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APPENDIX A.

RADIOCARBON DATES

During the course of this study three samples of organics were collected and submitted to the Geological Survey of Canada radiocarbon age-dating laboratory in Ottawa. In addition, two samples of bone from Section 7 (Figure 2) collected by Dr. C.R. Harrington at the National Museum of Ottawa were sacrificed for age dating.

Two samples of organics were collected at Section 3 (Figure 2). This is a 23 m thick sequence of gravels overlain by 6 m of silt. It is located approximately 0.6 km downstream from the confluence of Miller Creek and the Sixtymile River (63 ^{0} 59.7' N, 140 ^{0} 47' W), at an approximate elevation of 730 m.

SAMPLE NO.	AGE (B P)
GSC-3934.	> 42,000

Wood (sample HH-84-13: 9.9 g: *Picea* sp. (spruce) (unpublished GSC Wood Identification report No 84-34 by R. J. Mott). The sample was collected from a 40 cm thick bed of frozen organic silts and wood overlying 21.10 m of gravel (Figures 22-3). The sampled organics were overlain by approximately 2 m of well stratified gravel, 45 cm of peat

and 6 m of silt. The date is based on one 3-day count in a 5L counter. Collected by O. L. Hughes.

SAMPLE NO.	AGE (B P)
GSC-4032.	> 40,000

Sedge peat (sample HH84-13; 42.5 g) from a 40 cm thick bed 5.6 m below the top of Section 3. This peat is overlain by 5.6 m of massive, brown eolian silt interpreted as full-glacial loess and overlies 22.9 m of gravel. The sedge peat suggests impeded drainage, possibly due to permafrost. The sample was *in situ* , but contained plant macrofossils that could have moved by slope wash from the valley slope adjacent to the fan surface. The date is based on one 4-day count in the 5 L counter. Collected by O. L. Hughes.

These samples were a preliminary attempt to date the "paleo-Miller Creek gravels" and surface deposits from this site. Such greater than dates are common in the Yukon (for example see Blake 1984). However, they indicate that aggradation of the "paleo-Miller Creek gravels" was complete > 40,000 B P.

One wood sample and two bone samples were collected from the terrace

on the north side of the Sixtymile River valley (Section 7) (64 ^{0} 00'N, 140 ^{0} 44'W) at an approximate elevation of 710 m (Figure 23c, Plate 2).

SAMPLE NO.	AGE (B P)
Beta -13870.	26,080 ± 300

Wood (sample CHR 1985-9, rooted, in-place tree stump, *Picea* sp?) was collected from a unit of dark-brown, laminated and cross-laminated silts and muds overlaying 2.8 m of massive boulder gravel, stratified pebble gravel and cross-stratified sand. The wood was overlain by 1.0 m of interbedded matix-supported gravel and mud containing a rich assemblage of Pleistocene mammalian remains. These interbedded gravels and muds are overlain by 2 m of massive, brown silt. Triple the normal counting time was volunteered on this sample. Collected by D. Harrington, National Museums of Canada, Ottawa, Ontario.

SAMPLE NO.	AGE (B P)
Beta-8864	23,320 ± 640

Bone (sample NMC38 277, from a humerus of a western camel, Camelops hesternus). This sample was collected from a muddy matrix-supported gravel overlaying an approximately 3.0 - 4.0 m thick sequence of gravel, sand and mud. The matrix-supported gravel was overlain by approximately 4 m of massive, brown silt with minor wood, ice and matrix-supported gravel. Collected by Dr. C.R. Harrington, National Museums of Canada, Ottawa,

Ontario.

SAMPLE NO.	AGE (B P)
Beta-13869.	21,160 ± 280

Bone (sample CHR 1985 - 8, from the cranium of an adult male tundra muskox Ovibos moschatus). This sample was also collected at approximately 3.0 - 4.0 m in Section 7a from a mud matrix-supported gravel. Triple the normal counting time was volunteered on this sample. Collected by Dr. C.R. Harrington, National Museums of Canada, Ottawa, Ontario.

Sedimentary structures and textures of the lower massive ⟶ stratified gravels ⟶ cross-stratified sands at Section 7 are thought to represent a longitudinal bar in a "medial" braided river system. The fine-grained muds in which the wood sample (Beta-13870) was rooted represent suspension fall-out in the overbank adjacent to an active fluvial tract. The overlying mud-matrix supported gravels containing bone represent a stacked sequence of cohesive "plastic" debris flows derived from the steep slopes on the north side of the Sixtymile River valley. The bone was not *in situ* but was swept up as detritus from the slopes and incorporated into the debris flows. The overlying silts are thought to represent loess of late Wisconsinan full-glacial age.

The sample Beta13870 is the only *in situ* tree in the Yukon of full

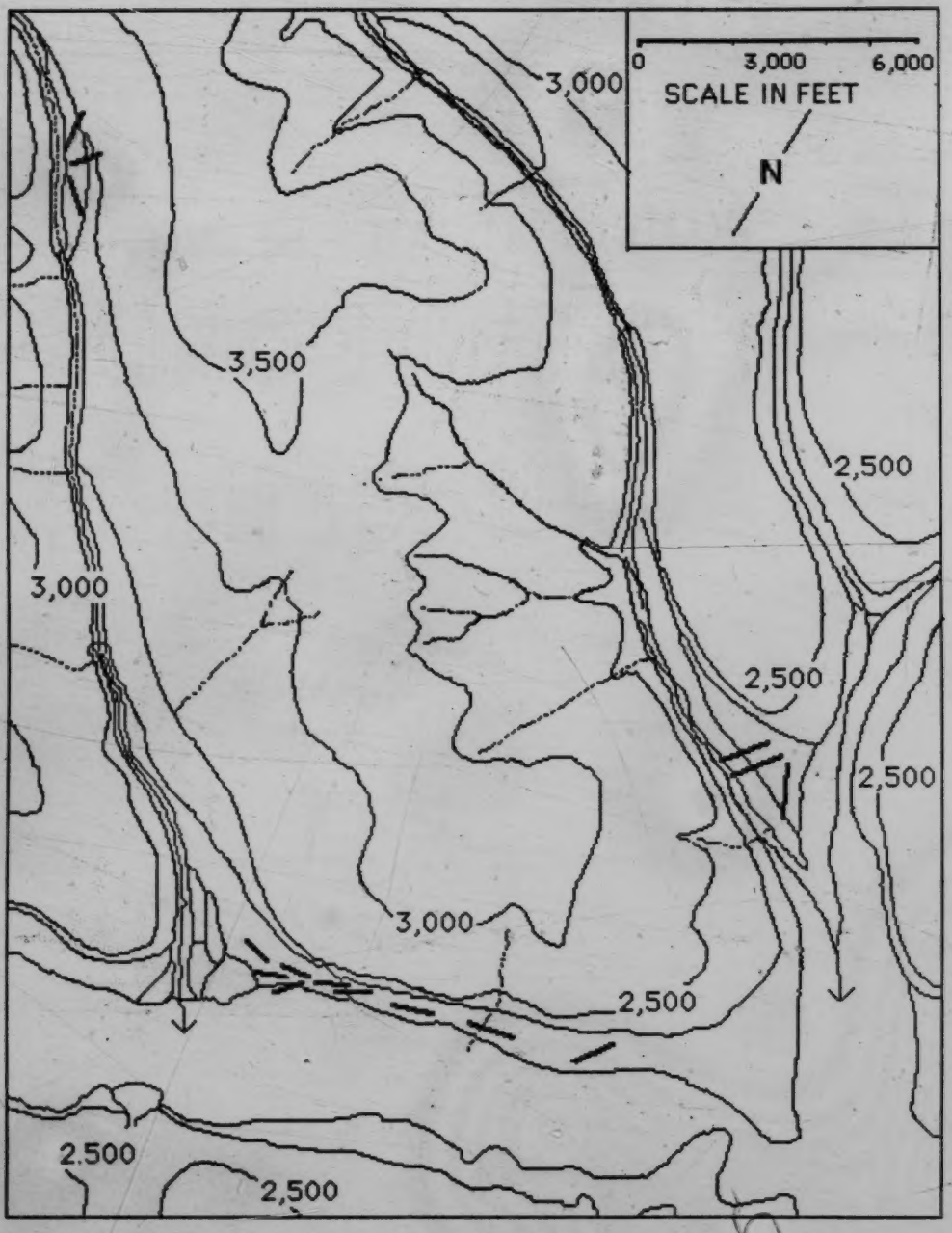


Figure 21. Map showing paleoflow directions inferred from dip-direction of a-b plane of b-axis imbricate flattish and elongate clasts.

glacial age. The presence of trees at that time suggests that the climate in the Sixtymile River area was sufficently warm and moist for the growth of trees, possibly as a gallery forest on inactive portions of the alluvial tract. The age and stratigraphic positon of this wood supports the two bone dates from the gravels above, which are thought to indicate the continued presence of a diverse assemblage of herbivorous mammals in the area until approximately 21,000 - 23,000 B P.

APPENDIX B.

SUMMARY STATISTICS OF GRAIN-SIZE DISTRIBUTIONS

Table 6. PERCENTAGE OF PHI VALUES FOR ALL GRAIN SAMPLES IN ORDER OF FACIES

FACIES 1 N =3

SAMP. NO.	SECTION	BED NO.	-1	0	1	2	3	4	5
8502A	1	1	58.1	9.6	8.0	5.6	4.5	4.0	10.3
8426	1	1	65.0	10.0	7.0	3.5	2.5	3.0	9.5
8502	1	1	37.3	8.0	6.7	5.4	6.2	10.2	26.5
			53.5	9.0	7.2	4.8	4.4	5.7	15.5

FACIES 2 N = 24

SAMP. NO.	SECTION	BED NO.	-1	0	1	2	3	4	5
8511-22	3	22	82.0	5.7	4.1	2.9	1.5	1.3	2.6
8511-14	3	14	76.8	7.0	6.9	3.7	1.7	1.3	2.7
8511-11	3	11	80.2	5.9	4.2	3.2	2.1	1.4	3.0
8511-1	3	1	65.1	8.4	7.5	6.7	4.6	3.2	4.4
8510	8	47-28	84.0	7.2	4.0	2.0	.7	.5	1.7
8509	8	42-5	60.1	16.1	17.8	6.9	1.0	.5	2.3
85107	6	85107-2	78.0	6.2	4.8	4.1	2.7	1.6	2.5
8454	5	17	58.8	11.7	8.6	12.4	5.2	3.6	5.2
8453	5	16	57.8	11.4	6.0	10.7	4.6	4.2	5.8
8449	5	2	51.7	9.4	9.5	9.2	7.1	5.4	9.4
8448	5	1	52.0	9.2	9.2	7.5	5.9	6.2	9.9
8441	8	6	52.3	10.3	11.5	9.3	4.5	3.5	8.3
8440	8	4	58	9.6	11.6	7.4	4.0	2.7	6.4
8437A	8	2	66.0	13.0	9.6	4.0	3.0	2.0	2.5
8433	8	5	60.0	10.0	10.0	8.2	4.3	2.7	4.5
8430	4	1	70.0	7.0	9.5	8.0	2.5	1.0	1.5

8427	2	1	73.5	7.5	7.5	5.0	3.5	2.0	2.0
8407	7	4	86.6	6.5	1.5	2.8	1.1	.5	.1
8424	4	1	70.0	10.0	7.5	4.5	3.0	2.5	.5
8406	6	1	77.3	9.0	6.9	3.0	1.5	1.0	1.5
8405	5	1	68.7	8.0	11.4	6.0	1.2	.5	4.0
8437B	8	3	48.5	12.0	13.0	22.0	6.0	4.2	5.0
8431	1	1	56.2	8.6	10	8.5	5.2	5.0	6.6
8401	1	1	69.0	10.0	12.5	6.0	1.5	.5	.1
			65.0	9.0	8.5	6.8	3.3	2.4	3.8

FACIES 3 N=7

SAMP. NO.	SECTION	BED NO.	-1	0	1	2	3	4	5
8457	4	4	88.8	.8	8.8	10.0	2.6	2.0	3.5
8450	5	3	54.1	13.7	10.2	6.5	4.7	4.5	6.1
8443	8	24	66.5	12.5	11.2	4.5	2.0	1.0	2.5
8425	4	1	84.0	2.7	3.0	3.0	2.5	2.0	3.0
8413	6	8	60.1	12.3	12.7	6.0	3.3	2.0	3.5
8412	6	7	71.5	8.5	7.5	4.8	3.0	2.0	2.7
8452	4	12	51	12.8	8.6	8.1	7.0	5.2	7.0
			68	9.0	9.0	6.0	3.5	2.5	4.0

FACIES 4 N=2

SAMP. NO.	SECTION	BED NO.	-1	0	1	2	3	4	5
85103	6	85103-3	70.5	3.4	3.6	2.7	1.5	2.6	15.6
8446	6	8	45.0	5.5	5.5	4.0	2.0	4.8	32.5
			58	6.0	4.5	3.5	2.0	4.0	24.0

FACIES 5 N=3

SAMP. NO.	SECTION	BED NO.	-1	0	1	2	3	4	5
8456	4	4	70.2	14.9	8.5	3.0	1.6	.7	1.0
8455	4	3	75.7	8.2	7.4	4.6	2.0	1.0	1.2
8402	2	2	73.0	8.7	8.7	5.5	1.5	.8	1.8
			73.0	10.5	8.0	4.5	1.5	2.0	1.5

FACIES 6 N=2

SAMP. NO.	SECTION	BED NO.	-1	0	1	2	3	4	5
8423	4	6	76.0	7.5	6.0	3.5	2.0	1.5	3.0
8415	5	2	31.7	19.3	26.2	10.0	4.2	3.6	4.8
			54	13.4	16.0	6.75	3.1	2.5	4.0

FACIES 7 N=13

SAMP. NO.	SECTION	BED NO.	-1	0	1	2	3	4	5
8512-4	7	8512-4	80.4	7.8	6.3	3.6	1.7	.1	.1
8512-1	7	8512-1	54.6	15.3	20.4	7.2	.1	.05	.1
8463	4	4H	66.9	11.6	10.8	6.3	.8	.2	.4
8462	4	4G	60.3	21.2	14.5	4.0	.5	.05	.4
8461	4	4B	66.6	9.4	14.8	6.2	.77	.15	2.1
8451	5	7	50.0	10.7	9.1	8.1	6.1	6.3	2.0
8442	8	2	59.5	10.5	10.0	8.0	4.5	2.5	4.5
8439	8	2	66.5	9.5	9.0	7.0	3.0	1.6	3.0
8411	5	1	48.5	11.0	11.5	9.5	6.5	7.2	6.0
VALUES FOR BEDS GREATER THAN 25% GRAVEL			61.5	11.9	9.7	6.0	2.7	2.0	2.0

8458	4	8	23.7	31.9	45.8	5.9	.5	.1	2.15
8434	8	4	16.7	24.0	30.3	16.5	5.0	3.0	4.5
8429	5	5	13.5	14.0	40.0	22.5	4.2	2.5	16.7
VALUES FOR BEDS LESS THAN 25% GRAVEL		18.0	23.3	38.7	15.0	3.3	1.9	7.9	
POOLED DATA FOR FACIES 7			50.6	14.7	17.0	8.2	2.85	2.0	3.5
FACIES 7A N=1									
8459	4	6	3.1	4.0	4.8	55.3	10.0	.6	30.2
FACIES 8 N=9									
SAMP. NO.	SECTION	BED NO.	-1	0	1	2	3	4	5
8438	8	3	80.5	4.0	4.5	4.0	2.0	2.0	3.0
8422	5	3	60.0	14.0	11.5	5.0	3.1	2.0	4.0
8421	6	3	68.0	4.0	6.5	10.0	5.0	3.0	3.2
8420	5	4	72.0	8.0	7.5	7.0	3.3	2.1	.5
8418	5	3	57.8	5.0	9.7	14.0	7.6	5.0	1.0
8417	5	1	56.0	10.0	8.5	9.5	5.8	5.0	5.1
.8436	8	6	61	9.5	13.5	10.0	2.4	1.0	1.5
8409	10	7	72.6	7.8	6.4	9.1	2.4	1.0	.7
8419	15	4	62	11.0	11.0	6.0	3.0	2.5	4.5
			65.5	8.0	8.5	8.0	4.0	2.0	2.0
FACIES 9 n=1									
SAMP. NO.	SECTION	BED NO.	-1	0	1	2	3	4	5
8432	8	2	.5	.5	.5	13.2	18.2	33.8	33.3
FACIES 10 n=1									
SAMP. NO.	SECTION	BED NO.	-1	0	1	2	3	4	5
8444	6	6	5.0	1.0	7.0	67.0	16.0	2.0	2.4

FACIES 11 n=1

SAMP. NO.	SECTION	BED NO.	-1	0	1	2	3	4	5
8513	7	3	2.5	2.5	5	10	35	35	10

FACIES 12n=2

SAMP. NO.	SECTION	BED NO.	-1	0	1	2	3	4	5
8447	6	9	1.7	1.5	2.2	3.4	3.0	7.6	80.3
8414	10	9	1.0	3.0	5.0	4.0	8.1	12.2	66.7
			1.35	2.25	4.7	3.7	5.9	10.0	73.5

APPENDIX B CONTINUED, HISTOGRAMS OF GRAIN-SIZE DISTRIBUTIONS

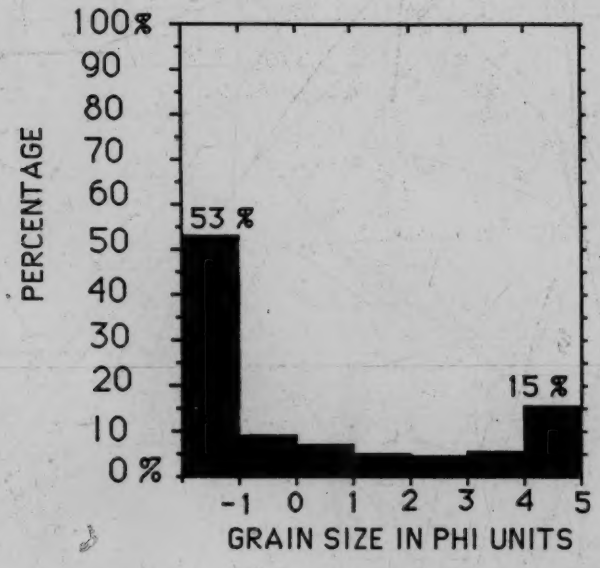


Figure 22-a. Histogram of the grain-size distribution for facies 1. N = 9. Mean a-axis length of the 10 largest clasts = 18.5 cm.

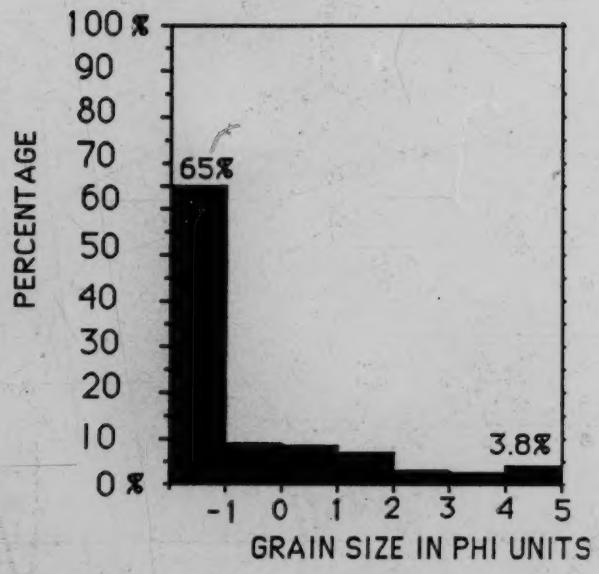


Figure 22-b. Histogram of the grain-size distribution for facies 2. N = 24. Mean a-axis length of the 10 largest clasts = 16.3 cm.

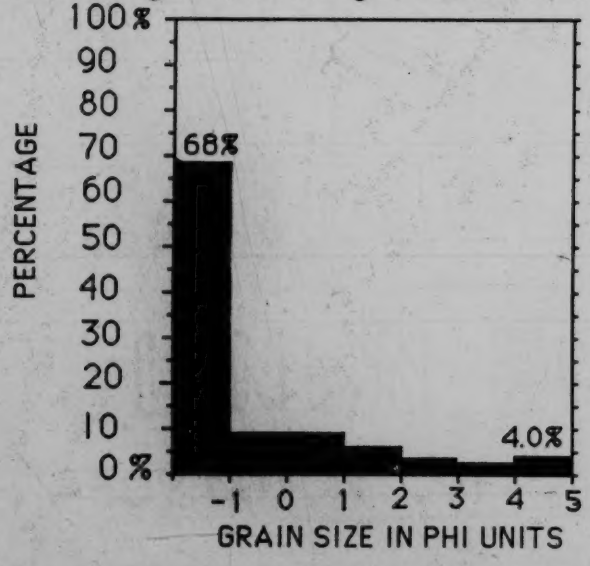


Figure 22-c. Histogram of the grain-size distribution for facies 3. N = 7. Mean a-axis length of the 10 largest clasts =15. 8 cm.

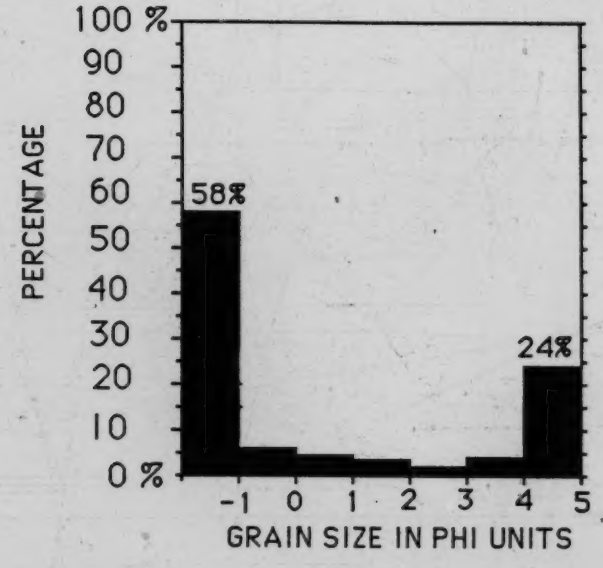


Figure 22-d. Histogram of the grain-size distribution for facies 4.

N = 2. Mean a-axis length of the 10 largest clasts = 12.0 cm.

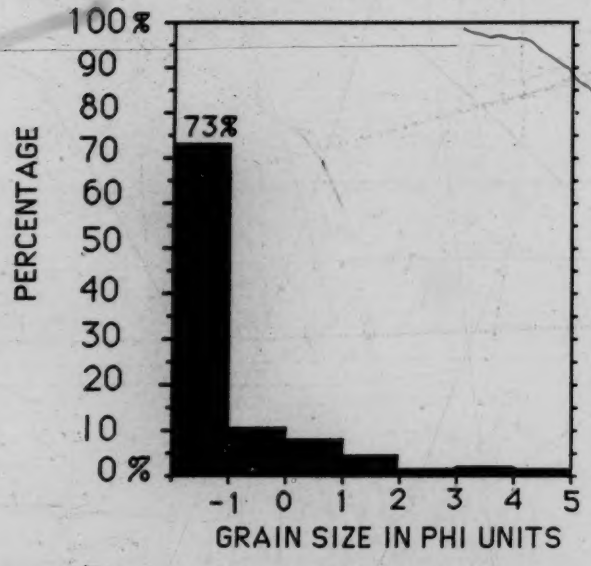


Figure 22-e. Histogram of the grain-size distribution for facies 5. N = 3. Mean a-axis length of the 10 largest clasts = 17.0 cm.

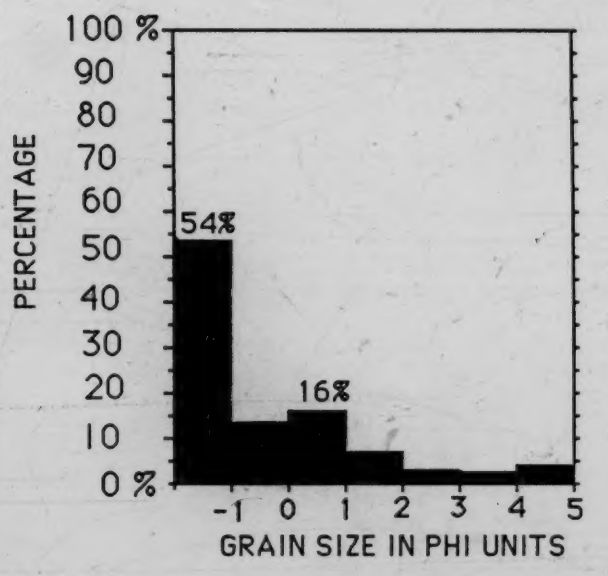


Figure 22-f. Histogram of the grain-size distribution for facies 6. N = 2.

Mean a-axis length of the 10 largest clasts =10.5 cm.

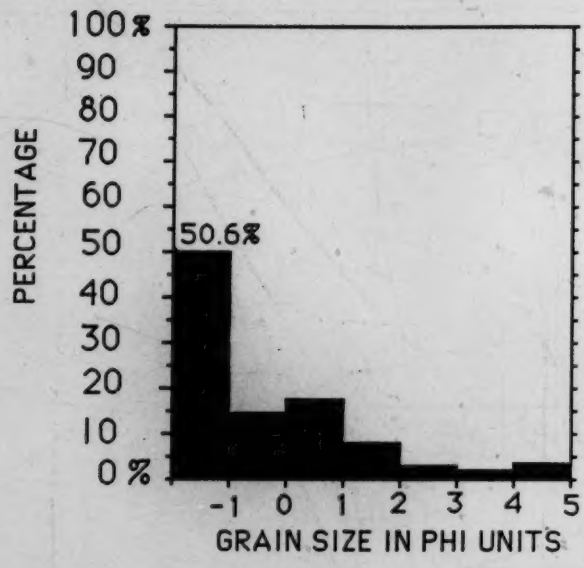


Figure 22-g. Histogram of the grain-size distribution for facies 7.N = 13.

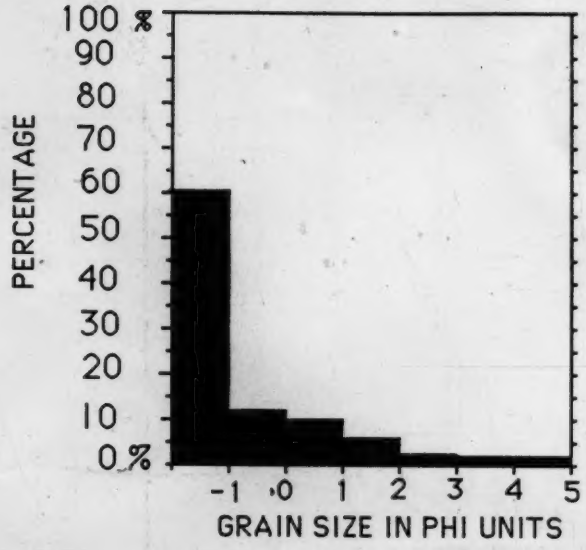


Figure 22-h. Histogram of the grain-size distribution for facies 7a. N = 9. Mean a-axis length of the 10 largest clasts = 7.1 cm.

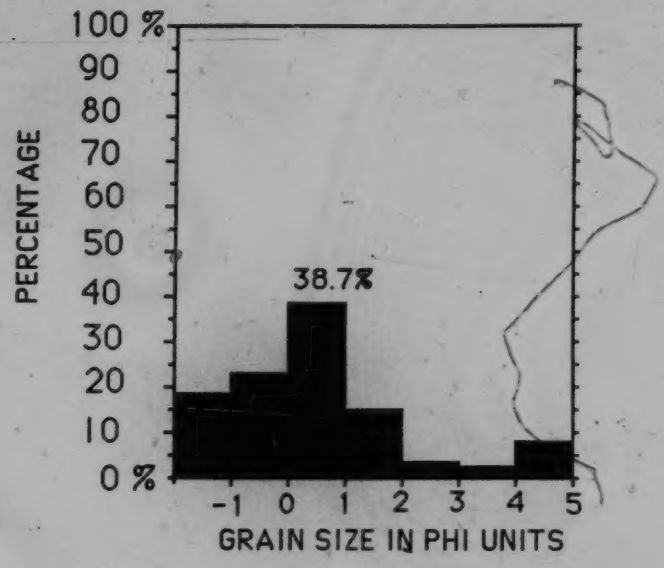


Figure 22-i. Histogram of the grain-size distribution for facies 7b. N = 3.

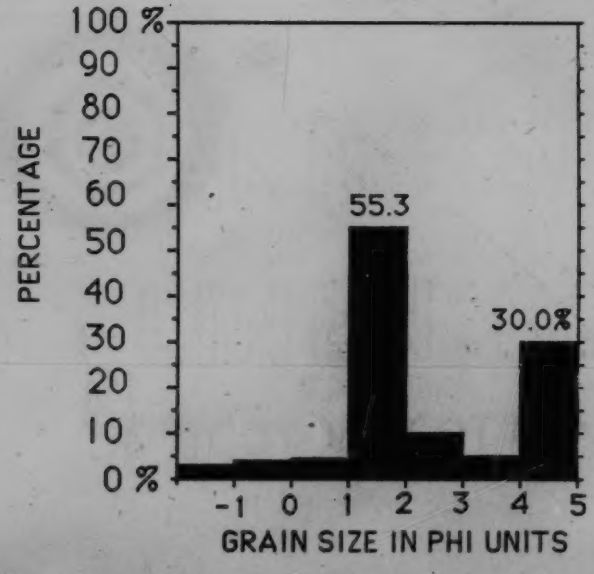


Figure 22-j. Histogram of the grain-size distribution for facies 7c. N = 1.

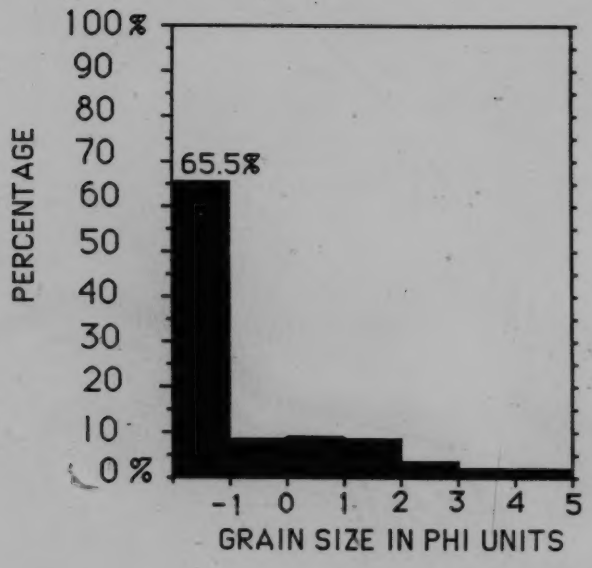


Figure 22-k. Histogram of the grain-size distribution for facies 8. N= 9.
Mean a-axis length of the 10 largest clasts = 11.3 cm.

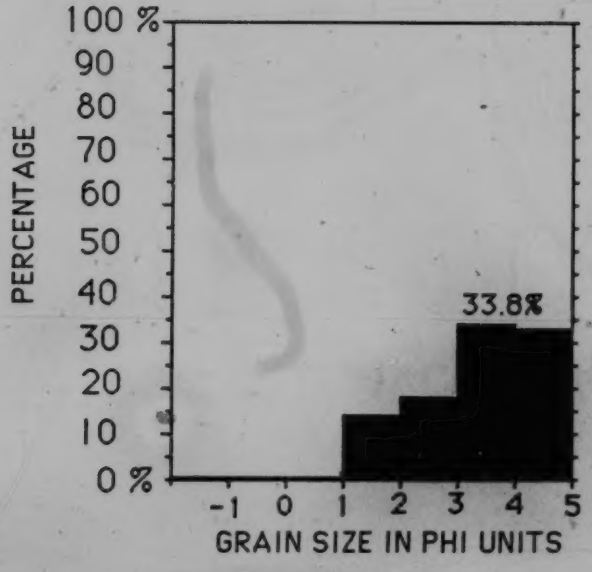


Figure 22-l. Histogram of the grain-size distribution for facies 9. N = 1.

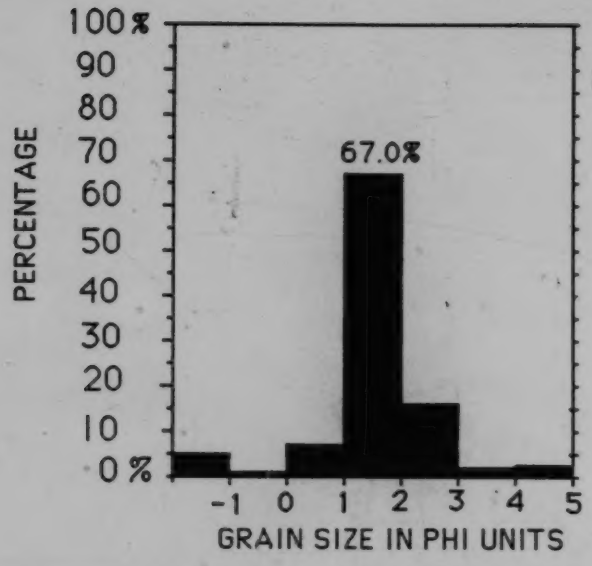


Figure 22-m. Histogram of the grain-size distribution for facies 10.

N = 1.

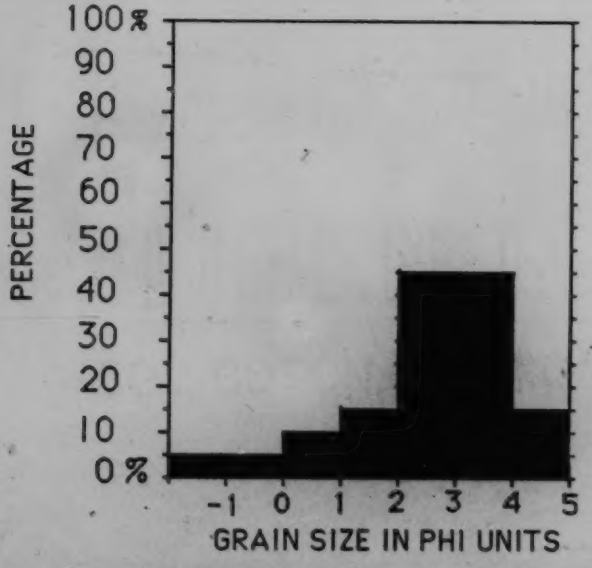


Figure 22-n. Histogram of the grain-size distribution for facies11 N = 1.

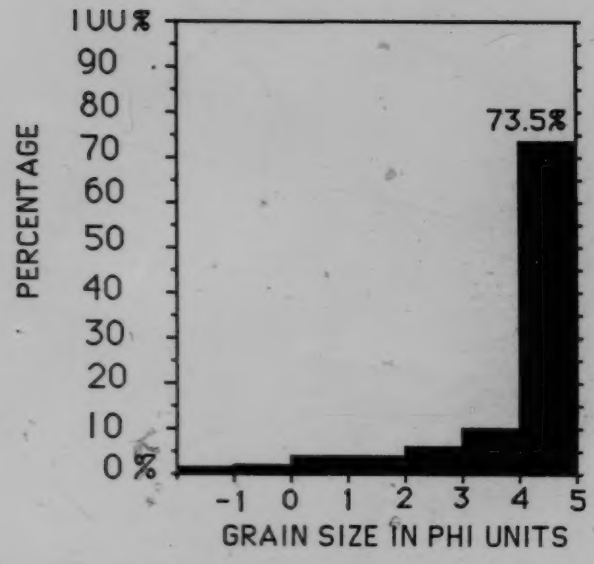


Figure 22-o. Histogram of the grain-size distribution for facies12.

N = 2.

APPENDIX C.
PALEOFABRICS

The strike and dip of 1,500 clasts were collected from 15 sites in 6 gravel facies. Rose diagrams of the a-and b-axis dip direction of clasts at four locations (sites 1-4) and rose diagrams for the b-axis only at eleven locations (sites 5-15) are shown in Figures 20a and 20b. The local paleoslope as indicated in Figures 20a and 20b was taken in the field. Table 2 is a summary of the imbrication ratio. Table 8 is a summary description of the sample location and the orientation of the clasts to the local paleoslope or valley trend.

APPENDIX D.

GOLD BULK SAMPLES

Table 7. AU BULK SAMPLES

SAMPLE 1 SECTION 1 FACIES 1
3 very fine and fine sand-sized grains of gold.

SAMPLE 2 SECTION 2 FACIES 2
12 fine to very-fine sand-sized grains of gold.

SAMPLE 3 SECTION 3 FACIES 2
No gold.

SAMPLE 4 SECTION 3 FACIES 2
30 grains of gold of which the largest was > 5 mm on the long axis.

SAMPLE 5 SECTION 4 FACIES 2.
1 very fine sand-sized grain of gold.

SAMPLE 6 SECTION 4 FACIES 2
No gold.

SAMPLE 7 SECTION 4 FACIES 3
2 very fine sand-sized grains of gold.

SAMPLE 8 SECTION 4 FACIES 2
5 very fine sand-sized grains of gold.

SAMPLE 9 SECTION 4 FACIES 2
3 very fine sand-sized grains of gold.

SAMPLE 10 SECTION 4 FACIES 5

3 very fine sand-sized grains of gold.

SAMPLE 11 SECTION 4 FACIES 7
3 fine sand-sized grain of gold

SAMPLE 12 SECTION 5 FACIES 3
3 very fine sand-size grains of gold.

SAMPLE 13 SECTION 5 FACIES 2
No gold.

SAMPLE 14 SECTION 5 FACIES 7
6 very fine sand-size grains of gold

SAMPLE 15 SECTION 5 FACIES 3

No gold.

SAMPLE 16 SECTION 5 FACIES 8

No gold.

SAMPLE 17 SECTION 5 FACIES 8

No gold.

SAMPLE 18 SECTION 6 FACIES 3
26 grains of gold from medium to very fine sand-size.

SAMPLE 19 SECTION 6 FACIES 3
1 fine sand-sized grain of gold.

SAMPLE 20 SECTION 6 FACIES 6

No gold.

SAMPLE 21 SECTION 6 FACIES 2
23 grains of gold all > 1 mm.

SAMPLE 22 SECTION 6 FACIES 2
1 fine sand-size grain of gold

SAMPLE 23 SECTION 6 FACIES 8
No gold.

SAMPLE 24 SECTION 7 FACIES 2
2 fine sand-sized grains of gold.

SAMPLE 25 SECTION 7 FACIES 2

6 grains of gold < 1 mm.

SAMPLE 26 SECTION 7 FACIES 2
12 grains of gold all < 2 mm

SAMPLE 27 SECTION 7 INTERBEDDED FACIES 6 AND 7C

No gold.

SAMPLE 28 SECTION 8 FACIES 2

6 grains of gold which are 1-2 mm, (nothing which is finer)

SAMPLE 29, SECTION 8 FACIES 2

No gold.

APPENDIX E.

CLAST LITHOLOGY

A study of clast lithology can serve three purposes: 1) it can be used to evaluate the provenance of the gravel by comparing the composition of similar gravel facies at different sections, and together with data collected on detrital mineral suites may indicate source rocks for mineralization, 2) a comparison between similar facies within the drainage basins may reflect proximal- to -distal variations in sorting and reworking (as estimated from the proximal- to -distal increase in resistant clasts such as vein-quartz and quartzites, 3) it is possible to compare clast composition between different beds within a single section to ascertain local point sources for the valley-fill. Trends found within a single sequence may then be related to variations in the amount of effective reworking between facies or, variations in source rocks during the period of gravel aggradation. Only a limited number of samples (17) were taken in the field; hence, this aspect is limited in scope to a comparison of the provenance of the gravel in the different drainages (Figure 21).

Some of the apparent trends from an examination of clast lithologies are as follows:

1. At Section 1 clasts are limited to locally-occuring bedrock types and are dominated by carbonaceous quartz schists.
2. At Section 3 clasts at the base of the alluvial fill are similar to the sample from Section 1 but also include some andesite clasts of the underlying bedrock.
3. At Section 4 magnetite metagranite, biotite granodiorite and amphibolite occur.
4. The base of Section 5 is compositionally similar to the base of Section 4 as both containin granitic clasts.
5. Debris-flow deposts from Section 6 contain only locally- derived andesite and basalt clasts.
6. Section 7 is compositionally similar to those Section 5 and 4, with dominantly granitic types.
7. Clasts from Section 8 are compositionally similar to Section 3, but vary in relative percentages.

The most important points are: 1) clasts from Section 1 are locally-derived and there is no evidence for transport of clasts into this area from outside the drainage basin; this is further evidence that this regions has not been glaciated, 2) clasts from Sections 4, 5, and 7 are similar in composition and indicate that the gravels underlying the distal portions of the alluvial fan are in fact "Sixtymile River terrace gravels, 3)

the relatively low percentage of andesite clasts at Sections 5 and 6 may be related to extensive reworking of these gravels, 4) the dominance of the locally-derived clasts in the debris-flow deposits is further evidence that they were derived from steep slopes immediately above the valley floor, and finally, 5) the clast lithology at Section 8 is similar to that at Section 3 indicating only slight variations in provenance between the two tributary drainage basins.

Table 8. Pebble Counts for Clast Lithologies

Section 1, lithofacies N =50		
QTZITE AND VEIN QTZ	8	16%
CARBONACEOUS MUSC QTZ SCHIST	33	66%
MUSC QTZ SCHIST	9	18%
Section 3 , lithofacies 2 N =50		
MUSC QTZ SCHISTS	10	20%
ANDESITE	11	22%
GRAPHITIC OR CARB MUSC QTZ SCHISTS	20	40%
QTZITE	9	18%
Section 3 , lithofacies 2 N = 50		
VEIN QUART AND QTZITE	10	20%
MUSC. QTZ SCHIST	3	6%
GRAPHITIC OR CARB MUSC QTZ SCHIST	34	68%
ANDESITE	3	6%
Total Section 3		
MUSC QTZ SCHISTS		13%
GRAPHITIC OR CARBONACEOUS MUSC QTZ SCHISTS		54%
ANDESITE		14%
QTZITE		19%
Section 4 , lithofacies 8 N = 50		
MUSC QTZ SCHIST	19	38%
QTZITE	7	14%
GRAPHITIC AND CARBONACEOUS SCHIST	15	30%
ANDESITE	2	4 %
BIOTITE GRANITE	7	14%

Section 4 lithofacies 2 N = 5

MUSC QTZ SCHIST	12	24%
QTZ METAGRANITE WITH MAGNETITE	14	28%
VEIN QTZ	11	22%
GRAPHITIC MUSC QTZ SCHISTS	11	22%
ANDESITE	2	4%

TOTAL SECTION 4

MUSC QTZ SCHIST	34%
QTZITE	13%
GRAPHITIC AND CARB SCHISTS	28%
ANDESITE	4%
BIOTITE GRANITE	23%

Section 5 lithofacies 4 N = 25

BASALT	3	12%
ANDESITE	22	88%

SECTION 5 lithofacies 8 N = 50

QTZITE	5	10%
ANDESITE	4	8%
MUSC QTZ SCHIST	28	56%
GRANITES	13	26%

Section 6 lithofacies 8 N =48

QTZITE	11	22%
CARB OR GRAPHITIC SCHISTS	6	12%
MUSC QTZ SCHISTS	17	34%
BIOTITE MAGNETITE GRANITE	16	32%

Section 6 lithofacies 2 N = 42

QTZITE	7	16%
GRAPHITIC SCHIST	9	21%
ANDESITE	3	7%
MUSC QTZ SCHIST	23	55%

TOTAL SECTION 6

QTZITE		18%
CARB OR GRAPHITIC SCHISTS		15%
MUSC QTZ SCHISTS		40%
GRANITE		23%
ANDESITE		3%
QTZ DIORITE		14%

Section 7 SECTION 28 N = 47

ANDESITE	6	13%
BIOTITE MAGNETITE QTZ META -GRANITE	18	38%
QTZITE	6	13%
GRAPHITIC MUSC QTZ SCHISTS	13	27%
MUSC QTZ SCHIST	4	9%

SECTION 7 lithofacies 1 N = 45

QTZITE	9	20%
GRAPHITIC SCHIST	14	31%
ANDENITE	10	22%
MUSC QTZ SCHIST	15	33%
QTZ DIORITE	7	15%

SECTION 7 TOTAL

QTZITE		15%
GRAPHITIC SCHIST		27%
ANDESITE		16%
MUSC QTZ SCHIST		19%
GRANITES		25%

Section 8 lithofacies 2 N = 50

MUSC. QTZ SCHIST	32	64%
GRAPHITIC MUSC QTZ SCHISTS	6	12%
QTZITE	7	14%
ANDESITE	4	8%
CONGLOMERATE	1	2%

Key: QTZITE: quartzite; QTZ: quartz; MUSC: muscovite; CARB: carbonaceous; N: number of pebbles counted.

Table 9. Fabric data: type of imbrication, sample location and comments on paleoflow directions

SAMPLE	FACIES	SECTION	TYPE	COMMENTS
1 (b-axis)	1	1	BIMODAL	Measured several m above bedrock in valley fill, there is no relationship between the imbrication and valley trend or local slope.
1 (a-axis)	1	1	UNIMODAL	Clasts imbricated downslope.
2 (b-axis)	1	1	POLYMODAL	Sample taken on a steep slope (>15) of valley wall, imbrication is intermediate in orientation between slope and channel.
2 (a-axis)	1	1	UNIMODAL	Possible imbrication up valley.
3 (b-axis)	1	1	UNIMODAL	Sample measured 2 m above bedrock in valley fill, imbrication is up-valley.
3 (a-axis)	1	1	POLYMODAL	Imbrication up-valley.
4 (b-axis)	4	6	BIMODAL	Sample measured at base of stacked sequence of interbedded facies 4 and 14, clasts imbricated down Sixtymile River valley and normal to slope.
4 (a-axis)	4	6	POLYMODAL	Questionable, but may show up-slope imbrication
5 (b-axis)	2	6	UNIMODAL	Sample measured in middle of gravels 1.75m from bedrock, shows a clear imbrication up Sixtymile valley.

6 (b-axis)	2	3	POLYMODAL	Sample measured at base of valley fill 1.5 m above bedrock there is no clear orientation.
7 (b-axis)	2	6	BIMODAL	Sample measured at top ofgravels approximately 2.5 m above bedrock, there is a bimodal distribution, but no visible relationship to trend of major valley or valley-wall slope.
8 (b-axis)	2	3	UNIMODAL	Imbrication up-valley.
9 (b-axis)	2	8	UNIMODAL	Sample at base of valley fill and is the most strongly imbricated but does not correspond to valley trend of Glacier Creek.
10 (b-axis)	2	8	POLYMODAL	Sample taken 3.5 m above bedrock, Similar to sample 9 imbrication is not related to valley trend.
11 (b-axis)	5	5	UNIMODAL	Sample taken near top of valley fill is orientated up major Sixtymile River valley.
12 (b-axis)	5	5	UNMODAL	Sample at 2.0m in middle of gravels on terrace shows imbrication near trend of Sixtymile River valley.
13 (b-axis)	8	8	BIMODAL	Sample taken in valley fill and like other samples at Glacier Creek imbrication is not related to valley trend and appears normal to it.
14 (b-axis)	8	5	UNIMODAL	Sample from 5m above bedrock in valley fill and shows orientation up paleovalley.

15 (b-axis)	8	3	BIMODAL	Sample at top of valley fill, one mode appears orientated up the palaeovalley the second is of questionable orientation.

APPENDIX F.

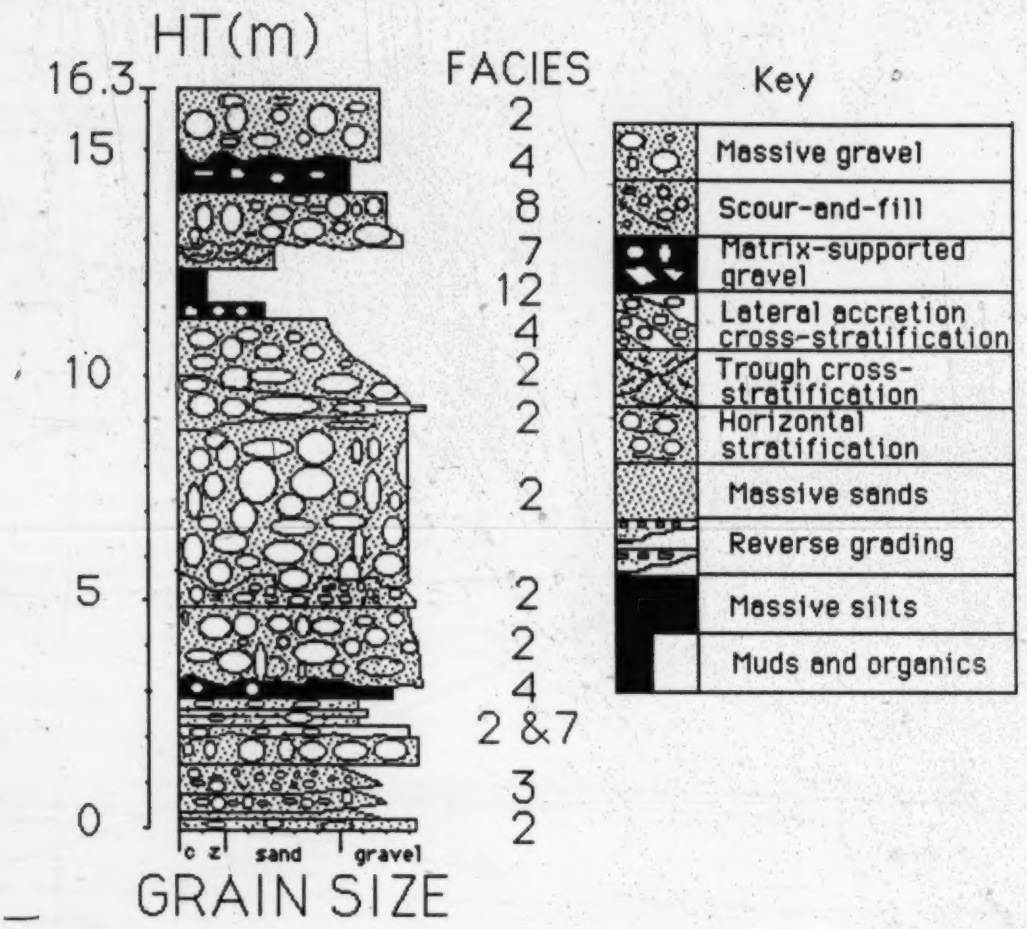


Figure 23 a Generalized vertical sequence at Section 2 in the Miller Creek valley

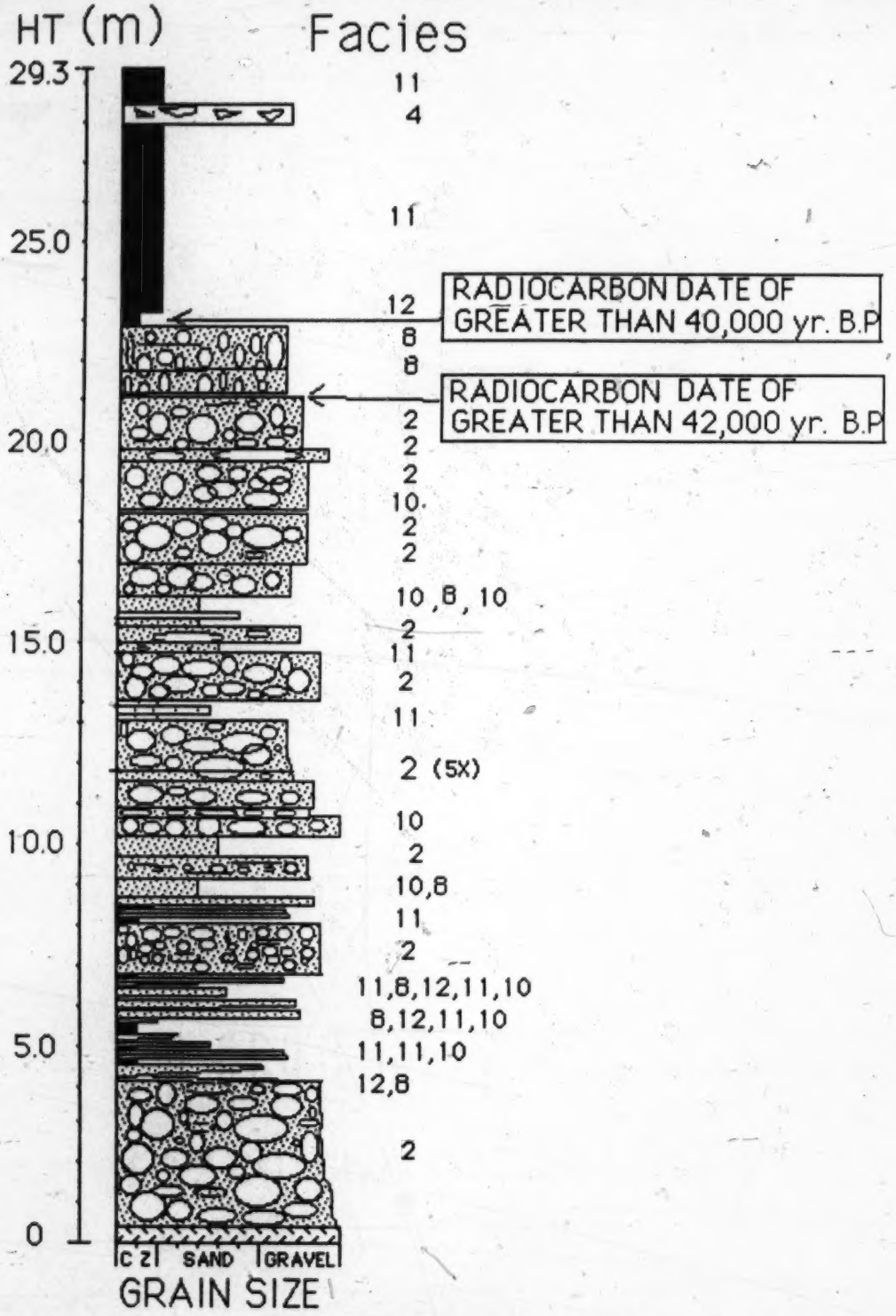


Figure 23b Stratigraphic Section 3 in the Miller Creek valley.

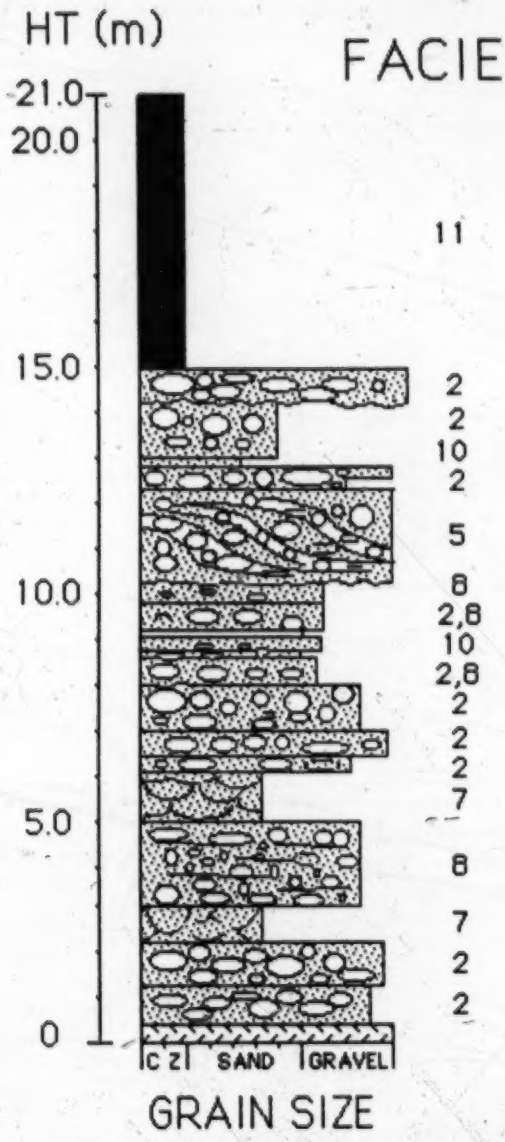


Figure 23 c. Stratigraphic column at Section 5 in the Sixtymile River valley.

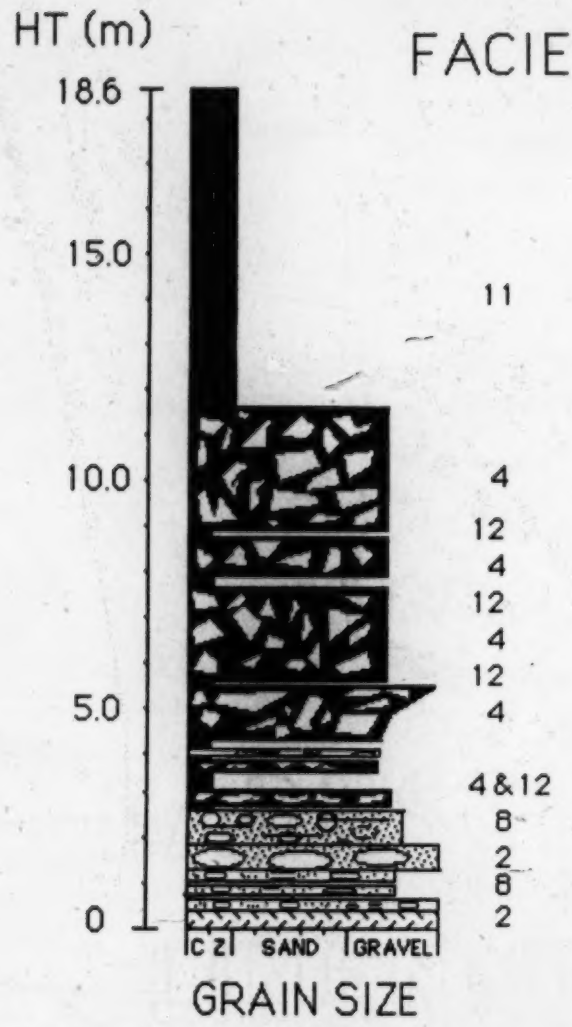


Figure 23 d Stratigraphic column at Section 6 in the Sixtymile River valley.

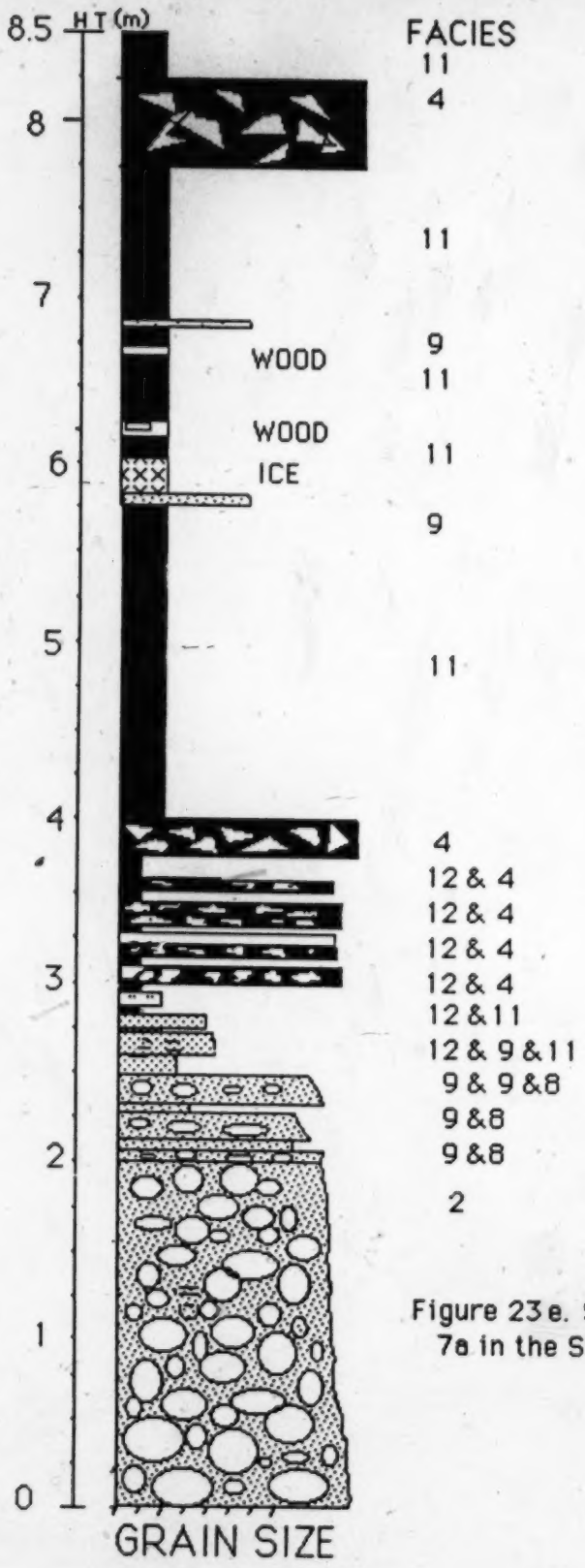


Figure 23e. Stratigraphic column at Section 7a in the Sixtymile River valley.

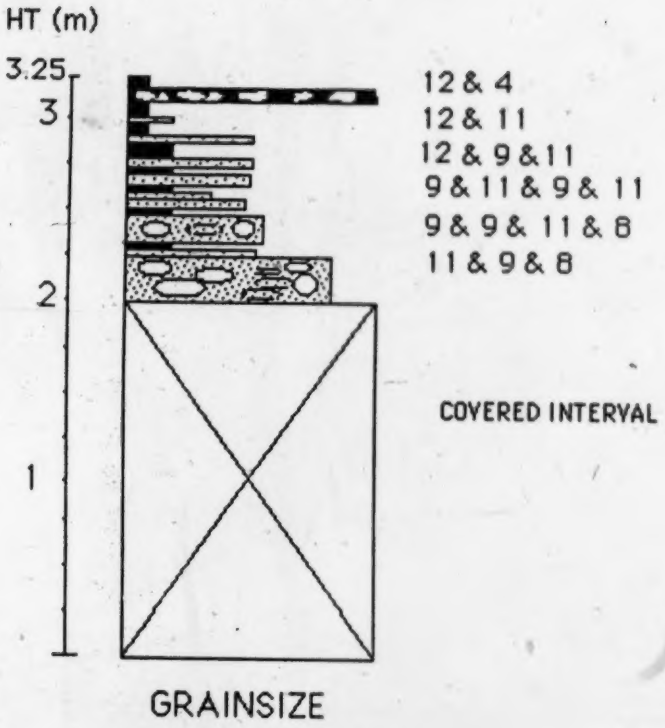


Figure 23f. Stratigraphic column at Section 7b in the Sixtymile River valley.

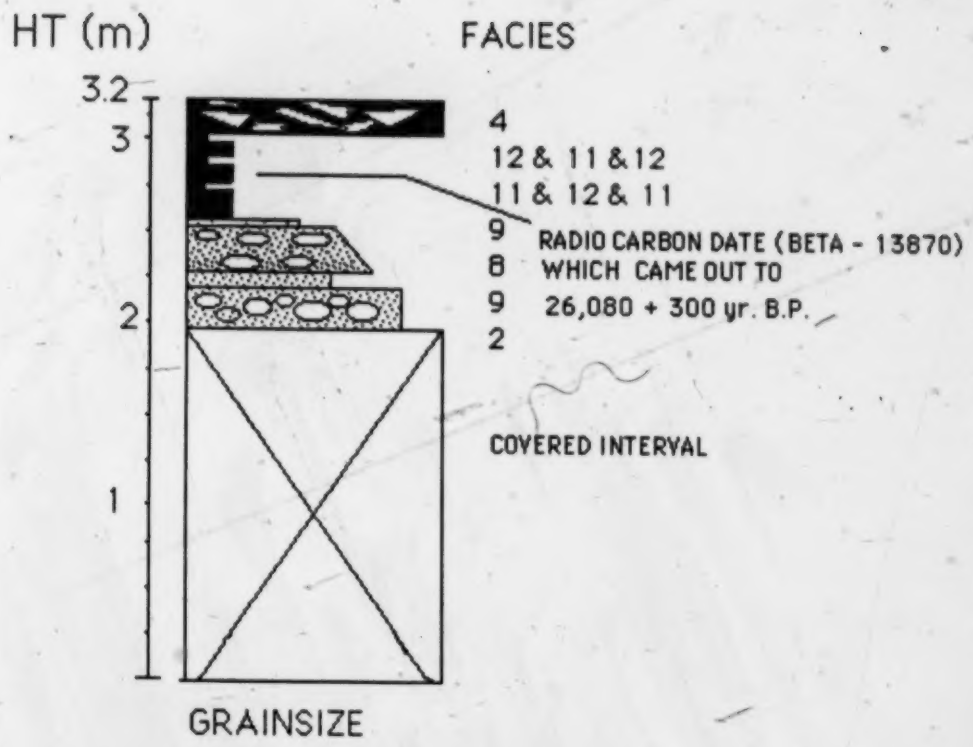


Figure 23g. Vertical column at Section 7c.

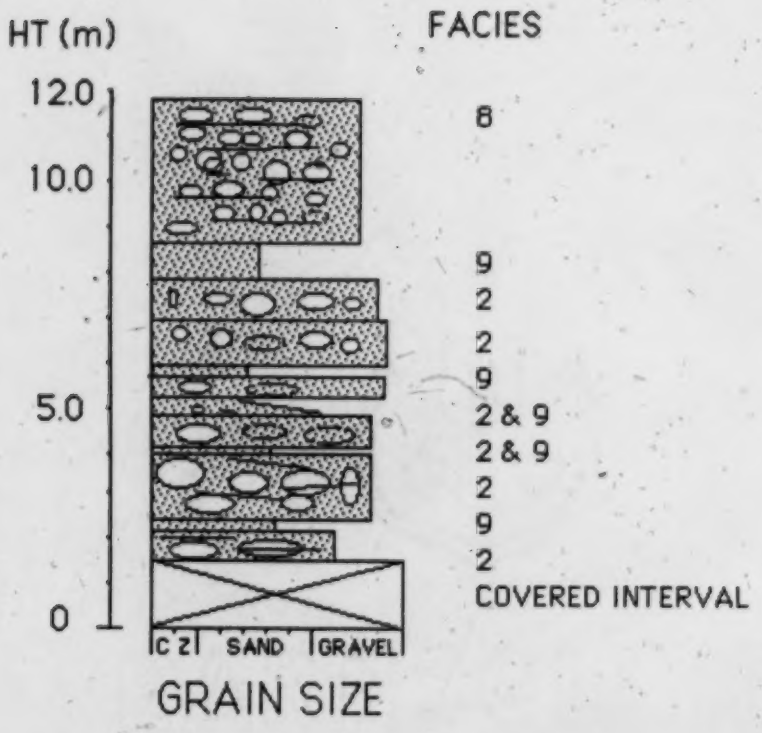


Figure 23h. Stratigraphic column at Section 8 in the Glacier Creek valley

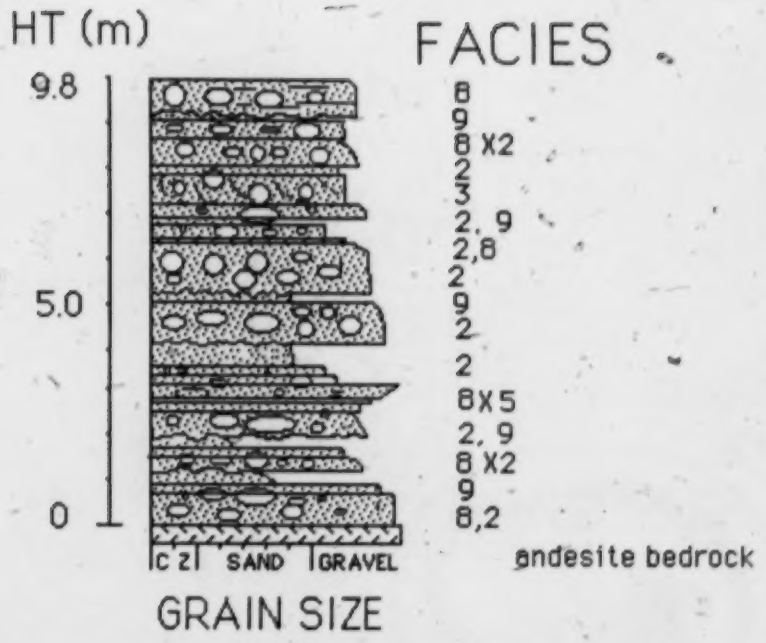


Figure 231. Stratigraphic column at Section 8 Glacier Creek valley.

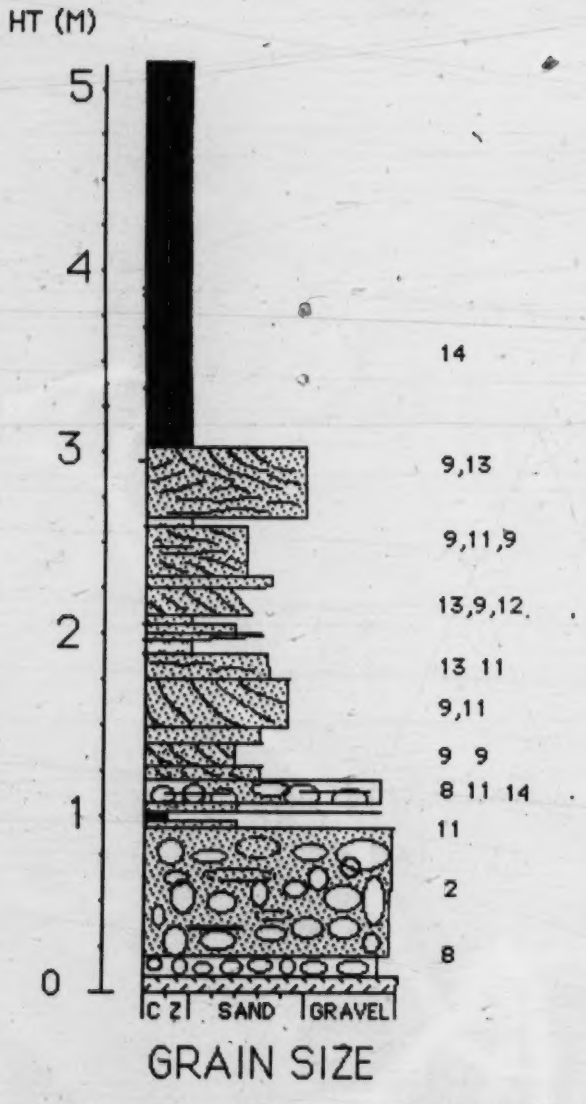


Figure 23j. Generalized vertical sequence at Section 10 in the Sixtymile River Valley.

Plate 1

A lens of ice in lithofacies 11 at Section 7 in the Sixtymile River valley. Note the nearly horizontal tail of ice suggesting the ice lens continued to grow as the silts slumped downslope.

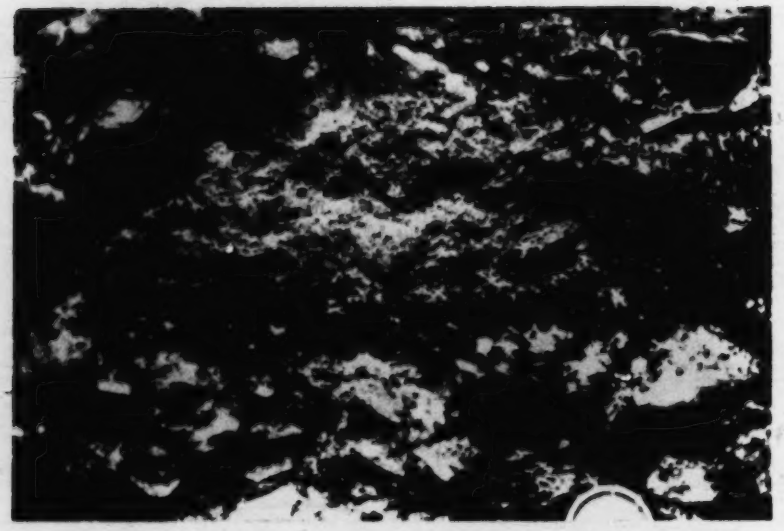


Plate 2 A small disorganized pocket of coarse sand in gravels of lithofacies 1 at Section 1 in the upper Miller Creek valley. Lens cap is 3.5 mm in diameter.

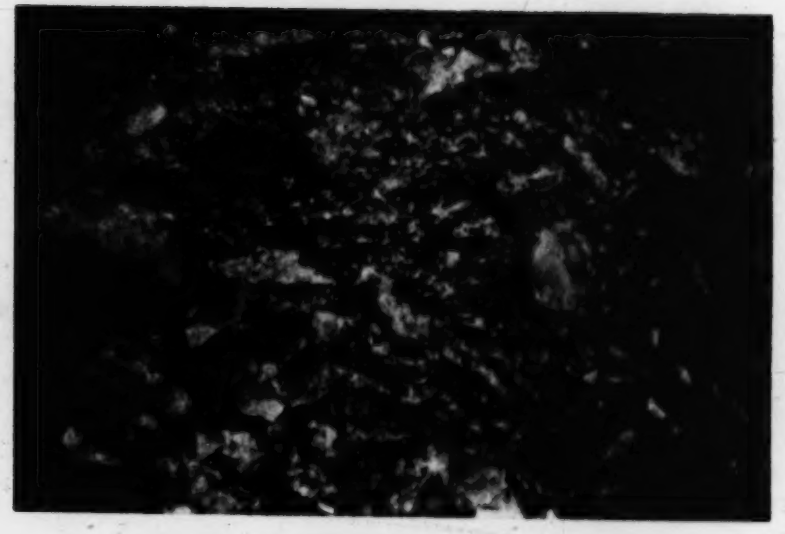


Plate 3 A cobble clast which is nearly a-axis vertical in gravels of lithofacies 1 at Section 1 in the upper Miller Creek valley. Note coarse sand to small pebble matrix in the lee of the large boulder. Flow direction from left to right. Pencil for scale.

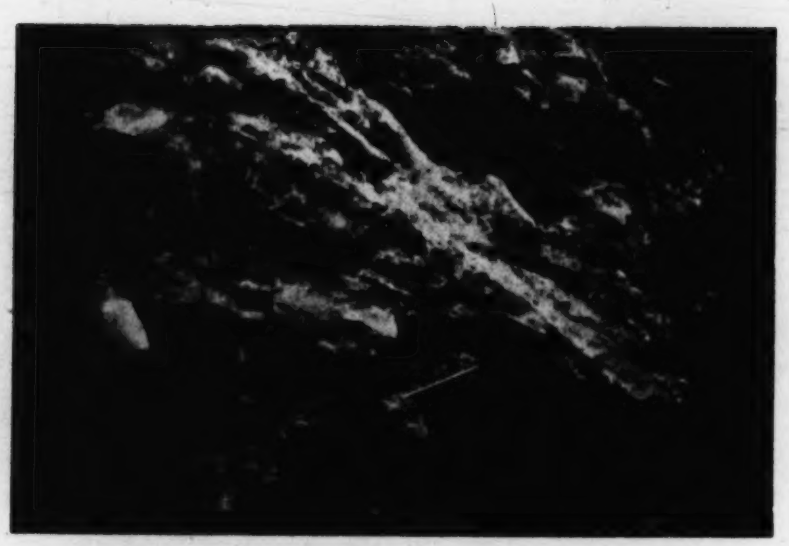


Plate 4

A large boulder > 1 m in length (near pencil) at the base of channel at Section 1 (in the upper Miller Creek valley), showing an orientation which is a-axis imbricate upstream. Paleoflow from right to left. Pencil for scale.

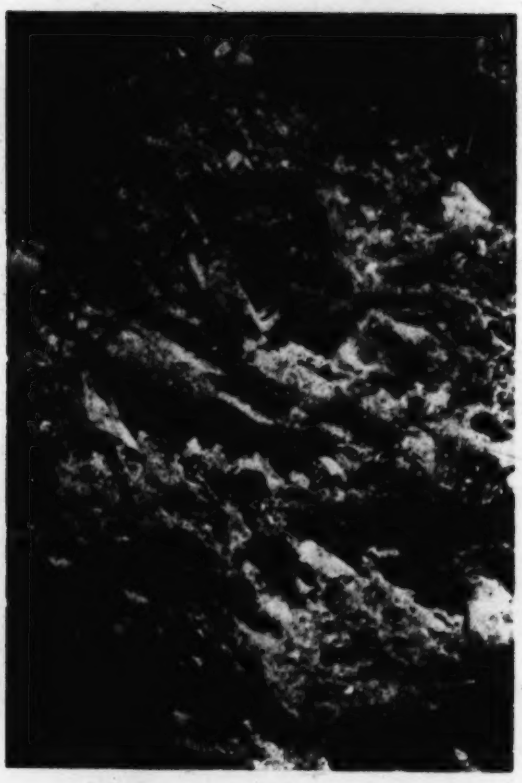


Plate 5 Steeply dipping a-axis imbricate clasts in the upper portions of the channel fill at Section 1 in the upper Miller Creek valley. Imbrication of clasts is attributed to post-depositional colluviation of a periglacial ice-wedge cast.

Plate 6 **Normal grading in a pocket of crudely-stratified openwork lithofacies 2 gravels at Section 3 in the Miller Creek valley. Pencil for scale.**

Plate 7

Poorly exposed right-hand margin of lithofacies 3 (scour-and-fill) at Section 6 in the Sixtymile River valley overlain by overbank muds of lithofacies 12. Subdivisions of scale on pole are 20 cm in length.

Plate 8 Example of stacked sequence of interbedded muddy matrix-supported lithofacies 4 gravels and lithofacies 12 muds at Section 6 in the Sixtymile River valley. This photo was taken above the lithofacies 3 gravels shown in plate 9. Subdivisions of scale on pole are each 20 cm in length.

Plate 9 Broken bone fragment occurring as a clast within a mud-matrix supported lithofacies 4 gravels at Section 7 in the Sixtymile River valley. Handle of geological hammer for scale.

Plate 10 Exposure of gravels at Section 4 in the Sixtymile River valley showing horizontally stratified gravels (lithofacies 8) in center of photo and portion of lateral accretion cross-stratified gravels (lithofacies 5) in the upper left corner of the photograph. Approximately 1 m of the bedrock is exposd at the base. Inferred paleoflow direction from right to left.

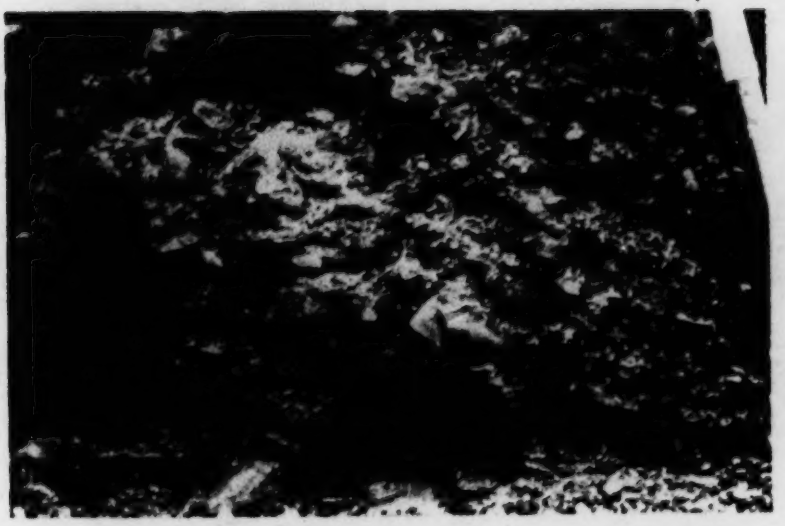


Plate 11

Example of poorly-sorted planar tangential cross-stratified gravel (lithofacies 6) overlying cross-stratified bed of poorly sorted pebble sand at Section 3 in the Miller Creek valley. Inferred paleoflow direction from left to right. Note portion of measuring pole for scale. Subdivisions of scale on pole are each 20 cm in length.

Plate 12

Sets of trough cross-stratified pebble gravel (lithofacies 7a) overlying massive gravels of lithofacies 3 at Section 4 in the Sixtymile River valley. Note portion of measuring pole for scale. Subdivisions on pole are each 20 cm in length.

Plate 13 Lower portion of trough cross-stratified pebbly sands (lithofacies 7b) at Section 5 in the Sixtymile River valley. Marker for scale.

Plate 14 Horizontally stratified gravels (lithofacies 8) at Section 4 in the Sixtymile River valley. Note the overlying trough cross-stratified sands and pebbly sands of facies 7.

Plate 15 Massive sands of lithofacies 9 at Section 3 in the Miller Creek valley. Camera lens cap for scale.

Plate 16 Interbedded coarse and massive sands capped by clays---granual gravel of facies 10 at Section 3 in the Miller Creek valley. Camera lens cap for scale.

Plate 17 **Massive aeolian silts (lithofacies 11) at Section 7 in the Sixtymile River valley in which traces of rootlets appear as black blebs. Handle of knife is approximately 10 cm long.**

Plate 18 Laminated to cross-laminated muds of lithofacies 11, muddy silts capping massive gravels at Section 7 in the Sixtymile River valley.

Plate 19 **Intraclast of massive gravel in lithofacies 12 muds at base of Section 7 in the Sixtymile River valley. Note rare small pebbles and wood fragment in muds. Subdivisions of pole on right for scale are each 20 cm long.**

Plate 20 View upstream showing channel-fill at Section 1 in the upper Miller Creek valley showing sloping bedrock of the Nasina Series in the foreground and on the slope of upper terrace. Note figure for scale in center of photo.

Ht (m)

5

4

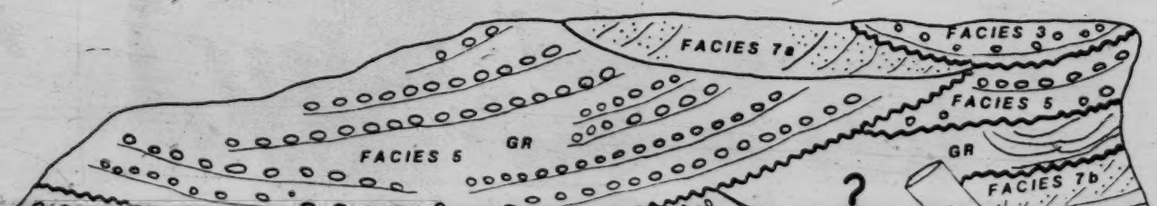
3

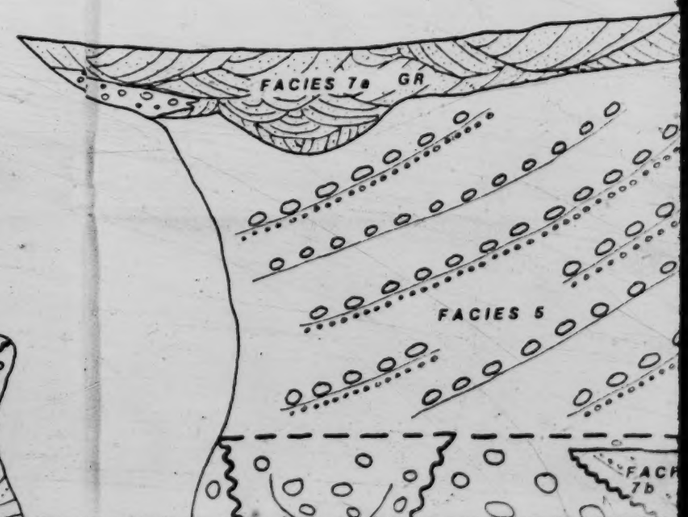
2

LEGEND

GRADATIONAL CONTACT	----
EROSIVE CONTACT	~~~~
FLAT TO WAVY CONTACT	~~~
LATERAL FACIES CHANGE	
COVERED INTERVAL	

BULK = 1 Ft^3 FOR AU
GR = GRAIN SIZE ANALYSIS
10 L = PEBBLE - 10 LARGEST
Pb = PEBBLE LITHOLOGY





SECTION 4 - SIXTY MILE RIVER

HORIZONTAL SCALE 1 cm = 1 m

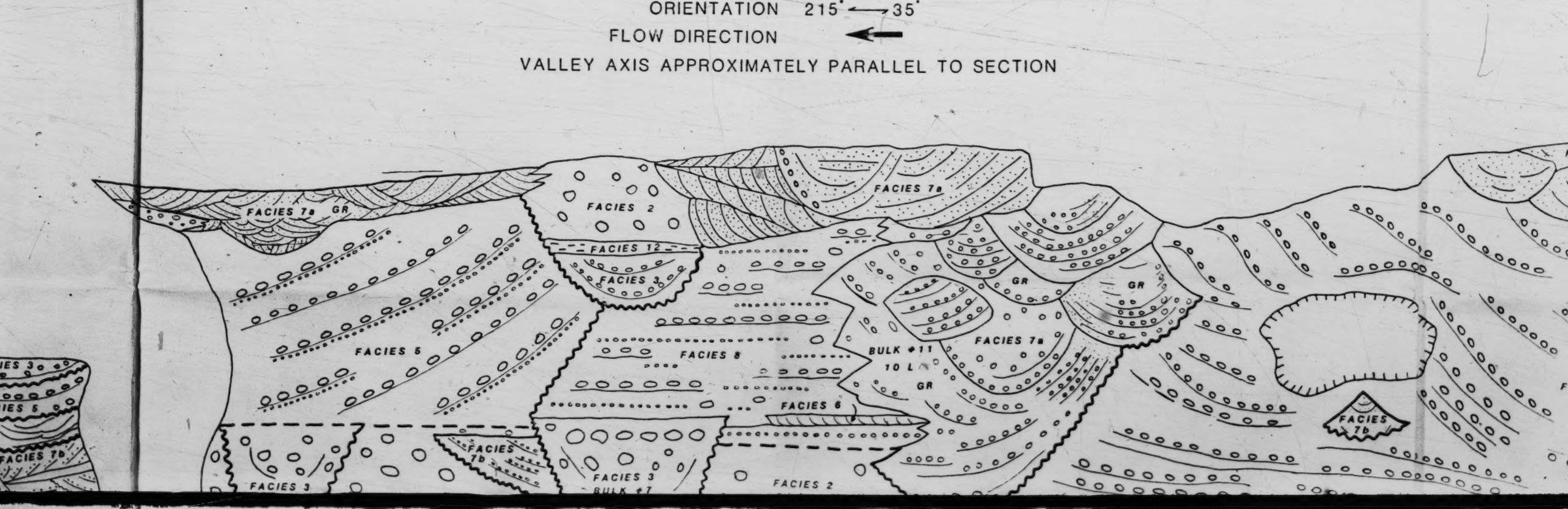
VERTICAL SCALE 1 cm = 0.25 m

VERTICAL EXAGGERATION X4

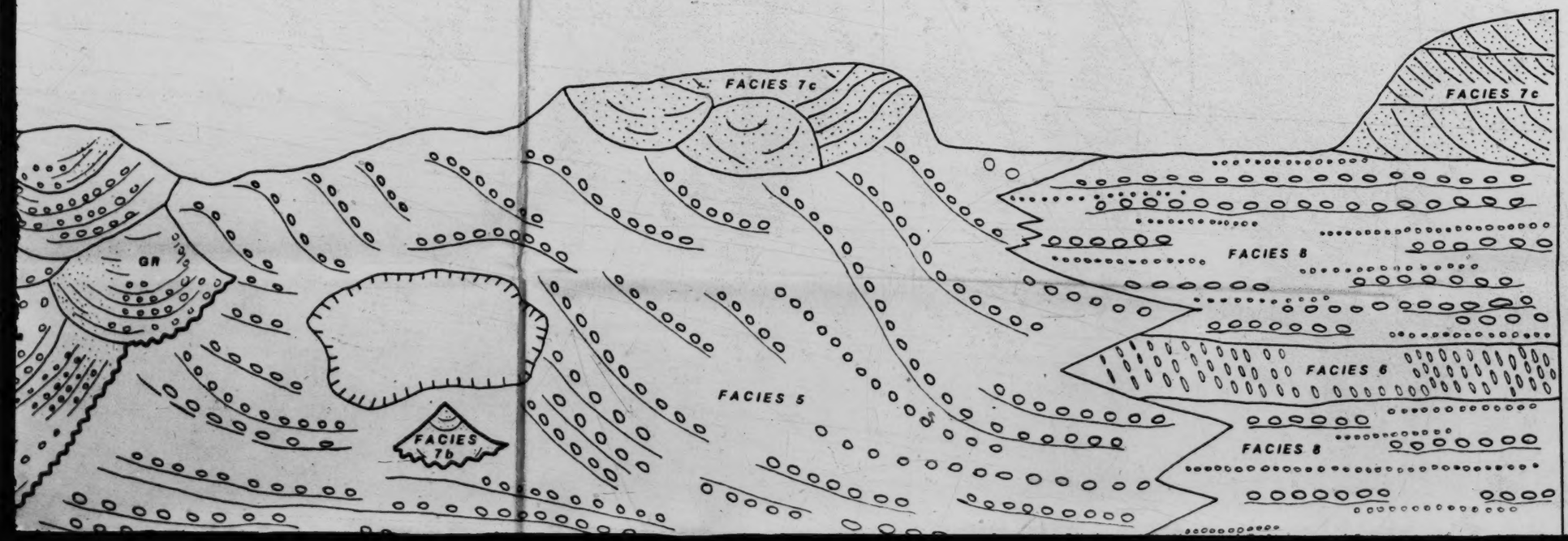
ORIENTATION 215° ⟷ 35°

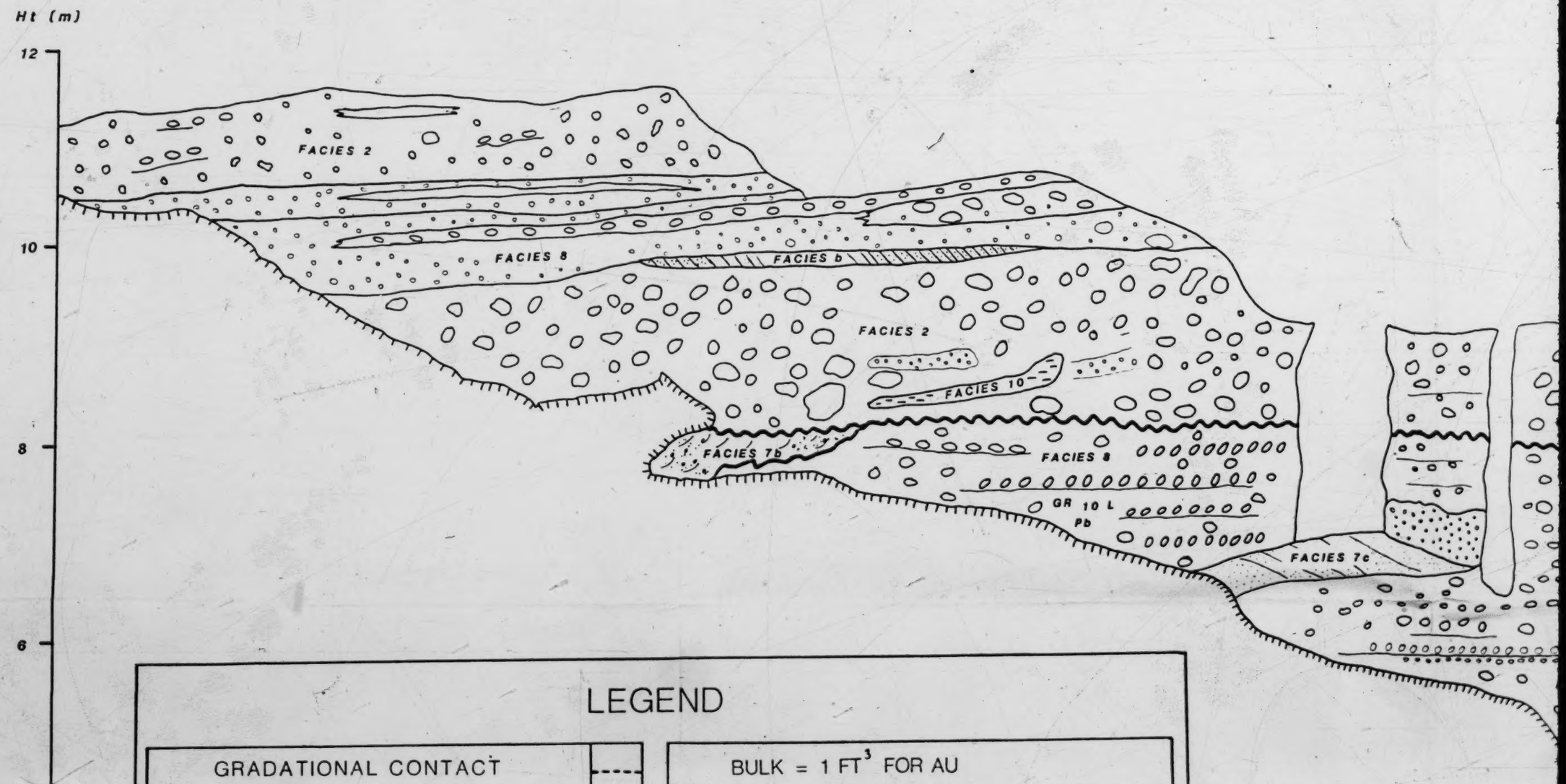
FLOW DIRECTION ←

VALLEY AXIS APPROXIMATELY PARALLEL TO SECTION



ON


FACIES 7c
FACIES 7c
GR
FACIES 8
FACIES 5
FACIES 8
FACIES 7b
FACIES 8



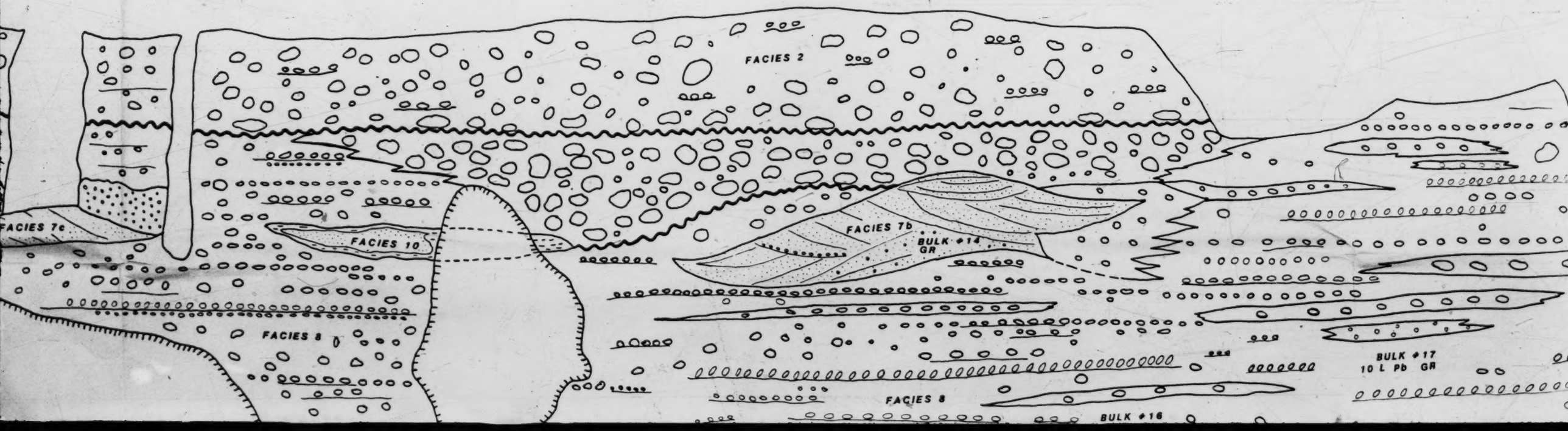
LEGEND

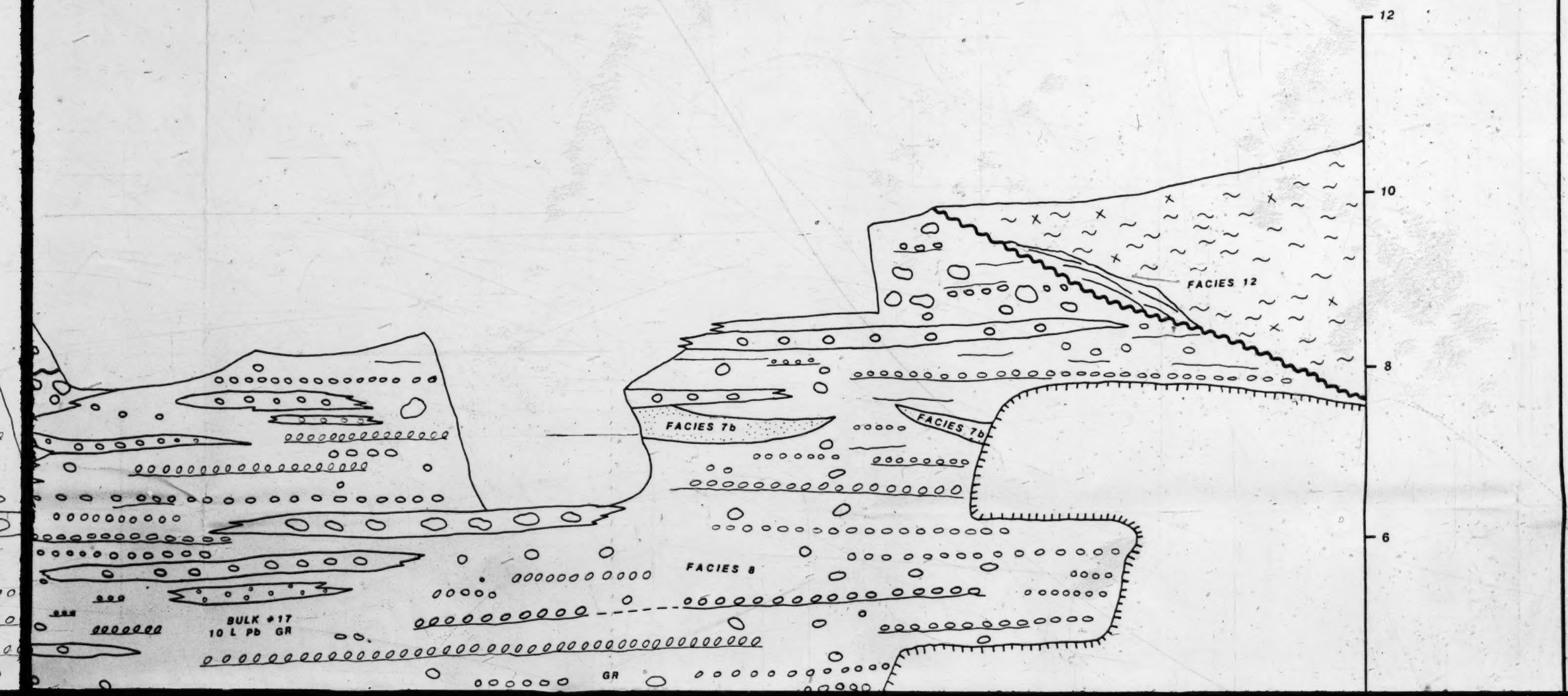
GRADATIONAL CONTACT	----	BULK = 1 FT^3 FOR AU

SECTION 5 - MILLER CREEK

-DISTAL ALLUVIAL FAN

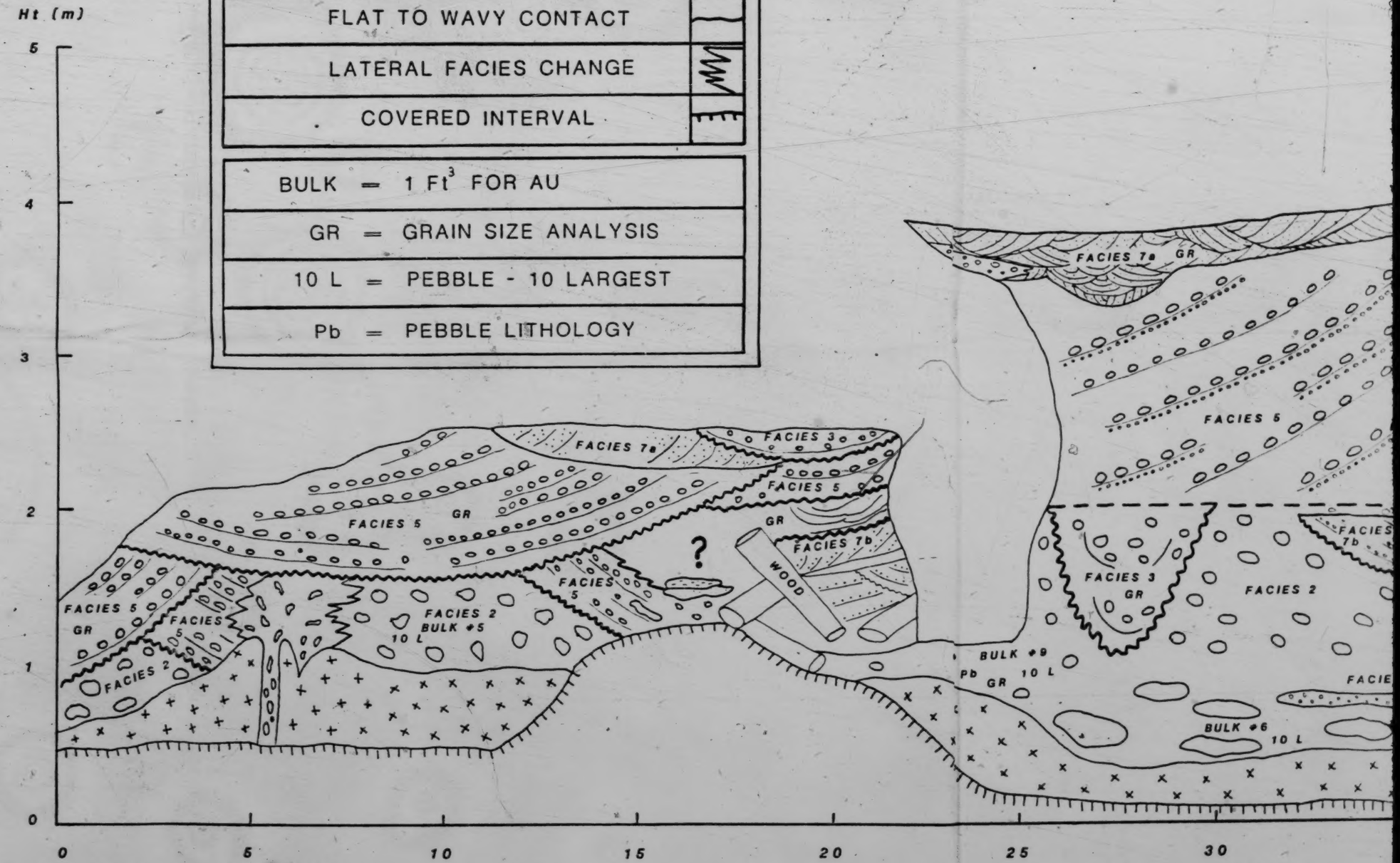
VERTICAL SCALE 2.5 cm = 1.0 m
HORIZONTAL SCALE 2.5 cm = 1.0 m
NO VERTICAL EXAGGERATION .
ORIENTATION 235° ⟷ 55°




12
10
8
6
FACIES 12
FACIES 7b
FACIES 7b
FACIES 8
BULK #17
10 L Pb GR
GR

EROSIVE CONTACT
FLAT TO WAVY CONTACT
LATERAL FACIES CHANGE
COVERED INTERVAL

BULK = 1 Ft^3 FOR AU
GR = GRAIN SIZE ANALYSIS
10 L = PEBBLE - 10 LARGEST
Pb = PEBBLE LITHOLOGY



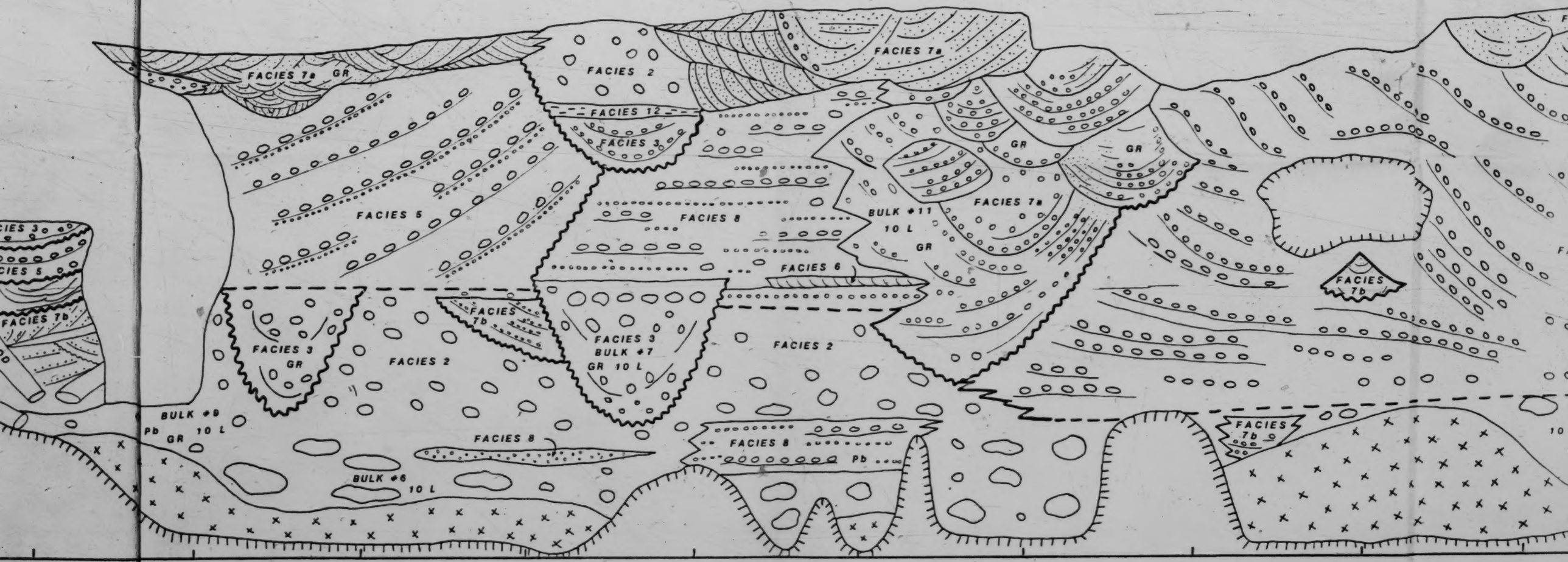
VERTICAL SCALE 1 cm = 0.25 m

VERTICAL EXAGGERATION X4

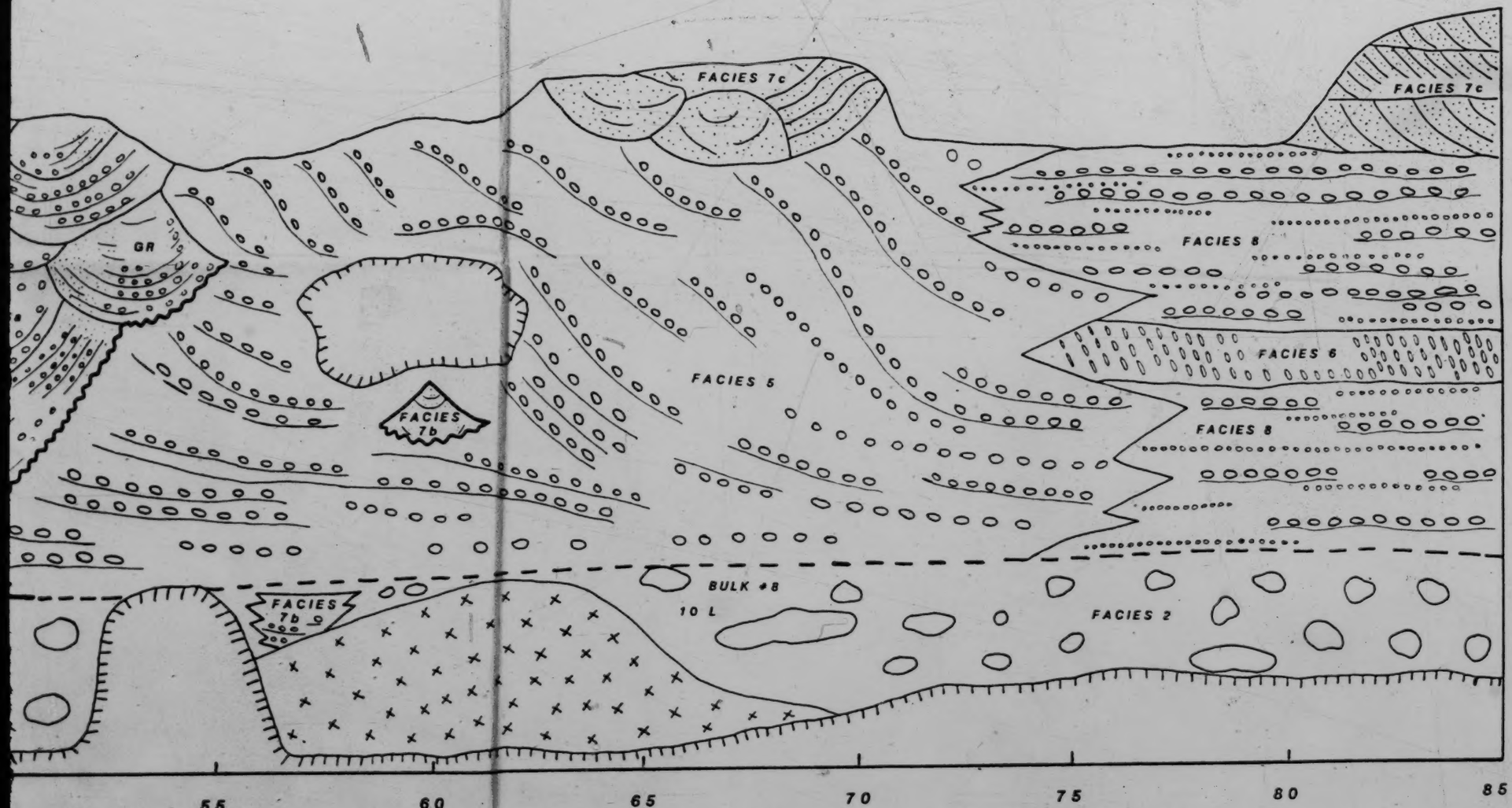
ORIENTATION 215° ⟷ 35°

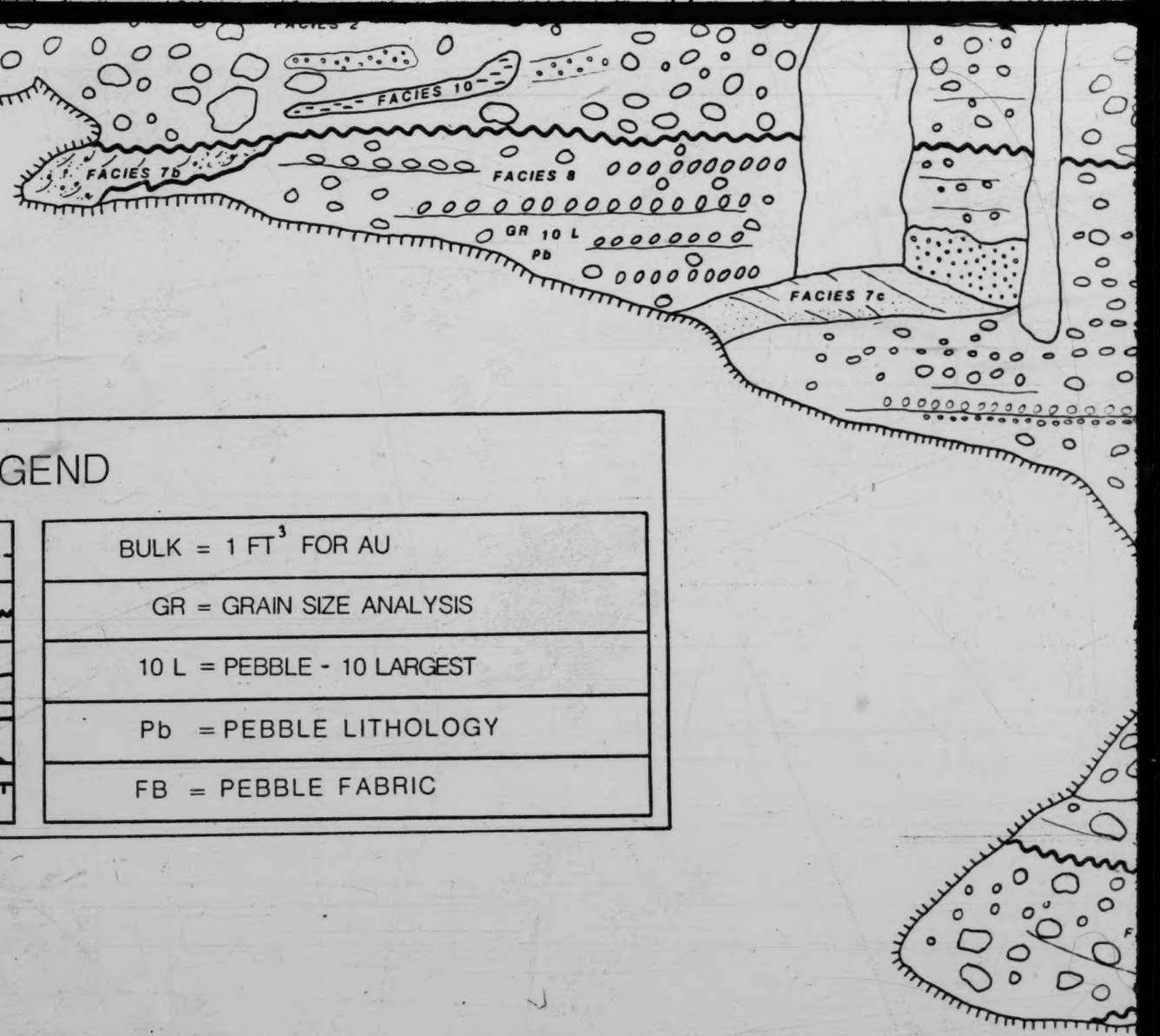
FLOW DIRECTION ←

VALLEY AXIS APPROXIMATELY PARALLEL TO SECTION



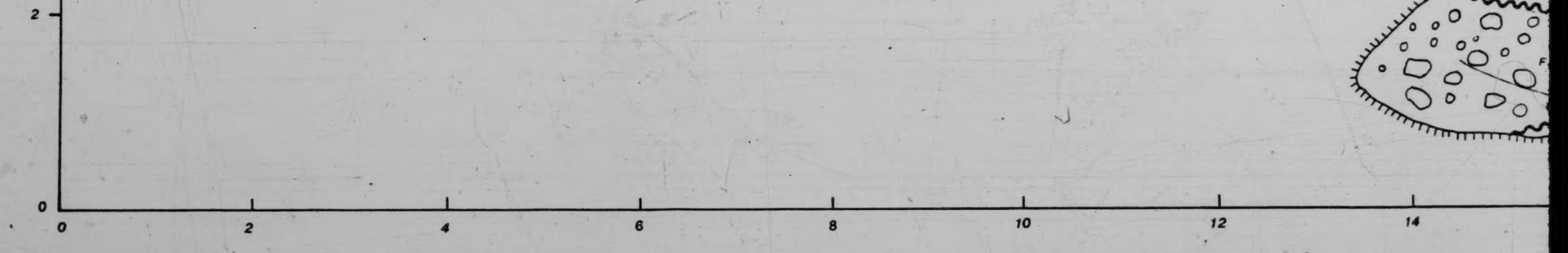
ON


FACIES 7c
FACIES 7c
GR
FACIES 8
FACIES 6
FACIES 5
FACIES 7b
FACIES 8
BULK #8
10 L
FACIES 2
FACIES 7b
55
60
65
70
75
80
85



LEGEND

GRADATIONAL CONTACT	BULK = 1 FT^3 FOR AU
SCOURED CONTACT	GR = GRAIN SIZE ANALYSIS
FLAT TO WAVY CONTACT	10 L = PEBBLE - 10 LARGEST
LATERAL FACIES CHANGE	Pb = PEBBLE LITHOLOGY
COVERED INTERVAL	FB = PEBBLE FABRIC



FACIES 2

FACIES 7c

FACIES 10

FACIES 7b

BULK #14
GR

FACIES 8

BULK #17
10 L Pb GR

FACIES 8

BULK #16
10 L GR
Pb

FACIES 7b

FACIES 2

FACIES 3

FACIES 12

FACIES 1

FACIES 2

FACIES 3

FACIES 2

GR

FACIES 2

GR

BULK #12
GR

FACIES 3

FACIES 3

FACIES 8

GR

FACIES 2

BULK #13

Pb

12 14 16 18 20 22 24 26 28 30

FACIES 12

FACIES 7b

FACIES 7b

FACIES 8

BULK #17
10 L Pb GR

GR

FACIES 2

FACIES 12

FACIES 7

FACIES 2

FACIES 7c

FACIES 2

FACIES 3

FACIES 7c

FACIES 3

BULK #15
GR

FACIES 2

8

6

4

2

0

28

30

32

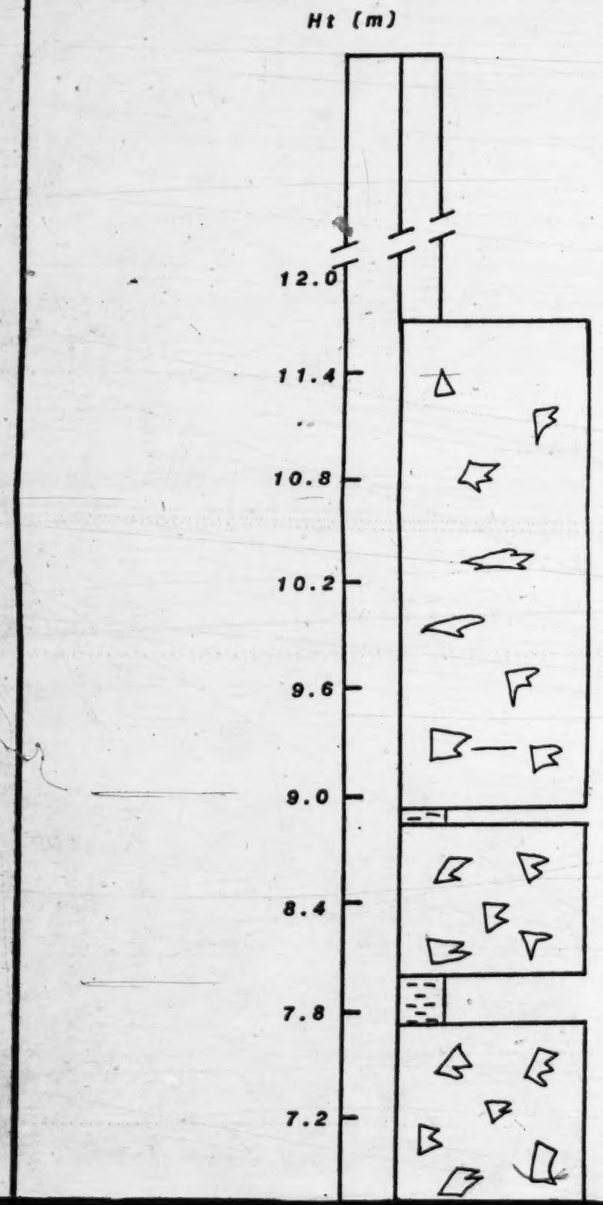
34

36

38

40

42


Ht (m)
12.0
11.4
10.8
10.2
9.6
9.0
8.4
7.8
7.2

SECTION 6 - SIXTY MILE TERRACE
BRAIDED ALLUVIUM

VERTICAL SCALE 10 cm = 3 m

HORIZONTAL SCALE 5 cm = 3 m

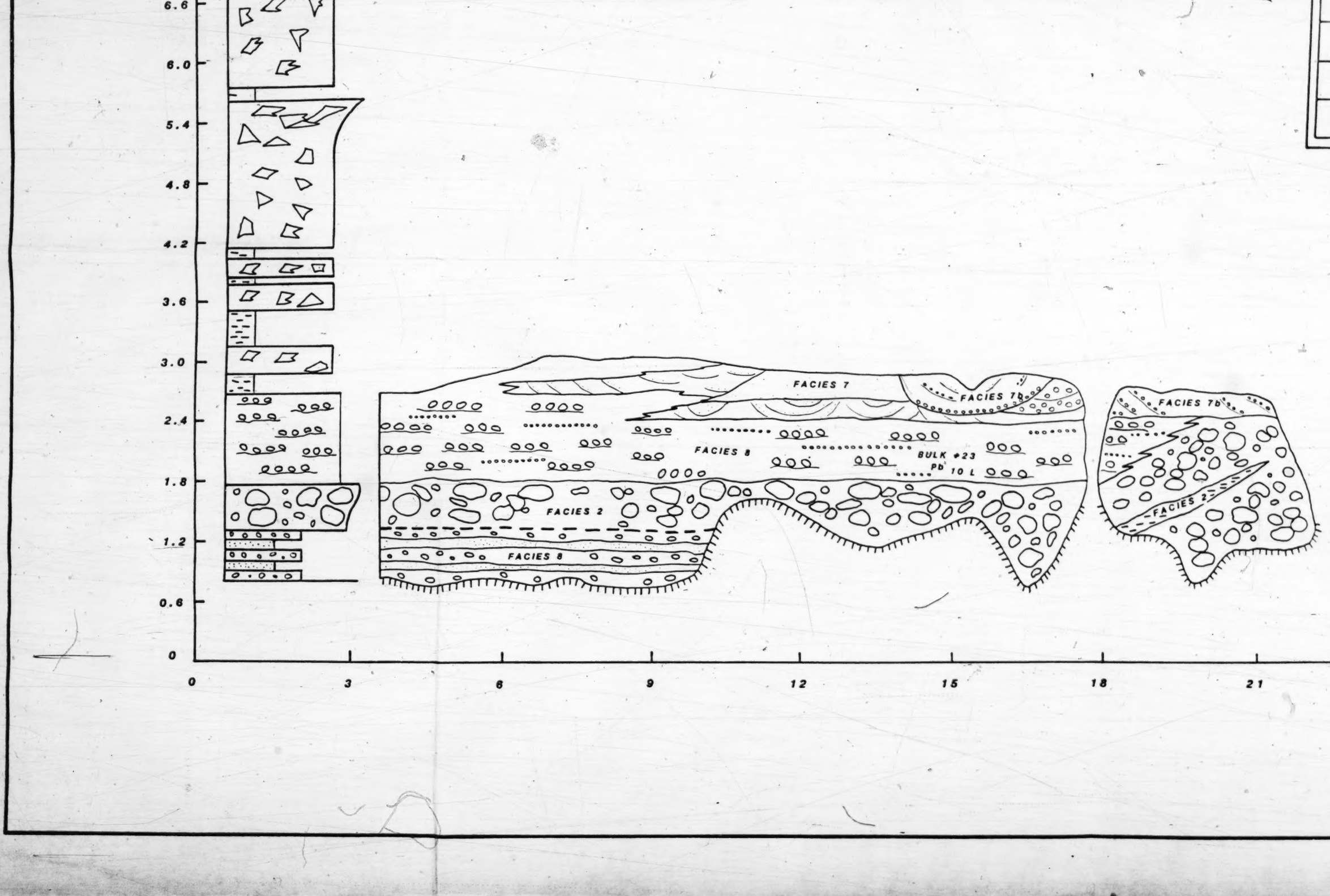
VERTICAL EXAGGERATION X2

ORIENTATION 215° ⟷ 35°

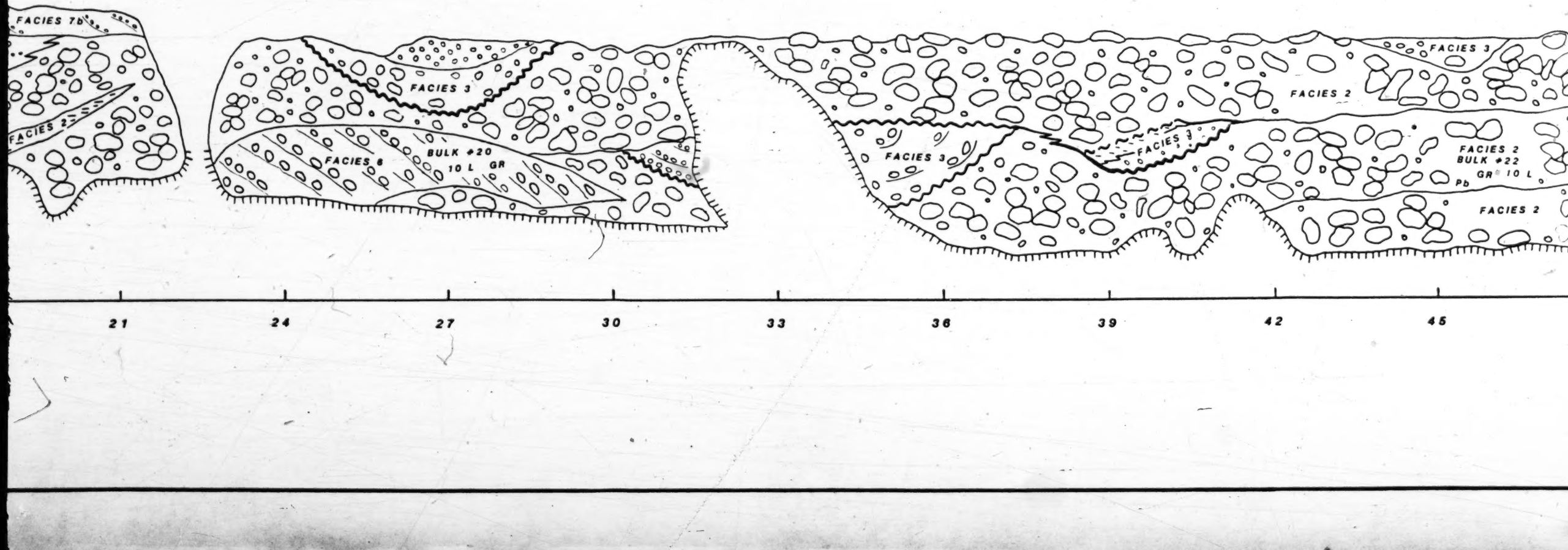
LEGEND

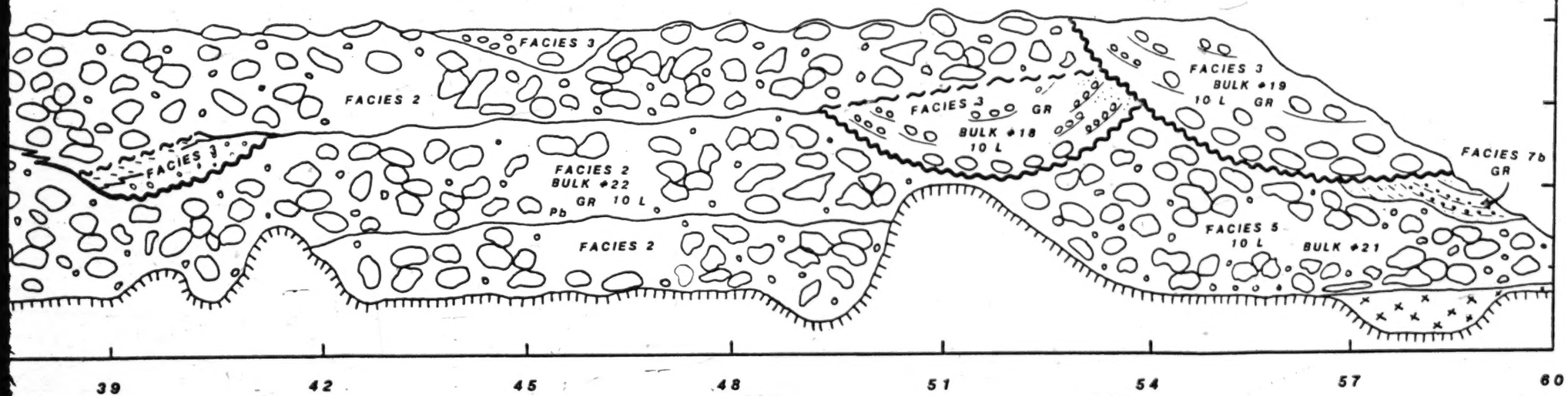
GRADATIONAL CONTACT ----

BULK = 1 Ft^3 FOR AU


6.6
6.0
5.4
4.8
4.2
3.6
3.0
2.4
1.8
1.2
0.6
0
0
3
6
9
12
15
18
21
FACIES 7
FACIES 7b
FACIES 8
BULK #23
Pb 10 L
FACIES 2
FACIES 8
FACIES 7b
FACIES 2

SCOURED CONTACT	GR = GRAIN SIZE ANALYSIS
FLAT TO WAVY CONTACT	10 L = PEBBLE - 10 LARGEST
LATERAL FACIES CHANGE	Pb = PEBBLE LITHOLOGY
COVERED INTERVAL	Fb = PEBBLE FABRIC




FACIES 3
FACIES 2
FACIES 3
FACIES 3
GR
BULK #19
10 L
GR
FACIES 3
GR
BULK #18
10 L
FACIES 7b
GR
FACIES 2
BULK #22
GR 10 L
Pb
FACIES 2
FACIES 5
10 L
BULK #21
39
42
45
48
51
54
57
60